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NYERE UNDERSØKELSER I OSLO-FELTET

AV

CHRISTOFFER OFTEDAHL

Ved professor W. C. Brøggers død i 1940 hadde geologene dannet seg et visst bilde av Oslo-feltet. Dette bilde var vesentlig basert på Brøggers publikasjoner. De mange detaljerte geologiske kart viste imidlertid at mange og store geologiske problemer fremdeles lå og ventet på sin løsning. Professor Holtedahl hadde da allerede i lang tid interessert seg for disse geologiske problemer, og helt vesentlig etter hans initiativ har en del av de yngre geologer arbeidet med Oslo-feltets geologi og petrografi siden ca. 1941. Som en av disse geologer skal jeg nå gi en kort oversikt over de resultater som supplerer det bilde vi har av Oslo-feltet fra Brøggers publikasjoner, i det jeg for det meste holder meg til egne upubliserte iakttagelser.

Lavaseriens stratigrafi ble vesentlig utredet av professor J. Schetelig. Det viser seg at i småområder som Schetelig ikke rakk å utrede, har vi også en langt mer detaljert stratigrafi enn rektangelkartene viser. Egil Sæther har i Nitedals-feltet påvist en serie svarende nesten fullstendig til Krokskogserien til og med E_2. Jeg har dertil funnet liknende serier i Glitrevanns- og Sandekalderaenes områder. Det har særlig interesse å fastslå at så langt vest som ved Hokksund har vi en omfattende serie: E_1, RP_1, RP_2, RP_4, RP_6, RP_7, RP_8, RP_9, E_2, RP_{11}, E_3, RP_{13}, og RP_{14}. Lavafeltet har således utvilsomt fortsatt langt videre mot vest.

Rombeporfyrene har hittil vært ansett for dannet ved spalteerupsjoner, og delvis ved arealerupsjoner, mens basaltene, i hvert fall den underste, må stamme fra de vulkaner vi har bevart i Oslo-essexittenes kupper. Lavaseriens blanding av basalt- og rombeporfyrstrømmer er da et merkelig fenomen, idet det da synes som om der har vært en veksling mellom to effusjonsformer og mellom effusjon fra to forskjellige magmaer. Problemet løses heller ikke av de siste to bidrag til erupsjonsmekanismen, nemlig Sæthers påvisning av at basaltene E_2 og E_3 har strømmet opp på overflaten gjennom talløse små åpninger, og mitt funn av en Oslo-essexitts samtidighet med en E_3 lava i Glitrevannskalderaen. Her har nemlig et lite område av Oslo-essexitt helt omgitt av basalt en finkornig grense mot en eldre varietet av listelava, mens den gjennomsettes av den yngre varietet. Således kunne også E_3 lava tenkes å stamme fra en vulkan. Imidlertid antyder variasjonene i den kjemiske sammensetning noe om erupsjonsmåten.

Det er et meget tydelig sprang i sammensetning fra den underste basalt E_1 til RP_1; liknende sprang er det fra RP_9 til E_2 og fra E_2 til RP_{11}. Derimot er RP_{12} en rektangelporfyr, en forløper for den mektige basalt E_3, og etter denne basalt har vi mektige rektangelporfyrdekker som alle har en sammensetning mellom rombeporfyr og basalt. Dette gir følgende bilde av magmautviklingen, idet en bygger på hypotesen om basaltmagmaet som det primære magma.

I tidlig permisk tid ble det dannet spalter i jordskorpen fra Midt-Norge ned til Skåne enten ved tensjon eller skjærspenninger. Gjennom disse sprekker steg magma fra det basaltiske substratum opp og dannet et større magmakammer oppe i kontinentblokken, og noe magma steg opp til overflaten og dannet basalten E_1. Det ble så en lang periode av ro, hvorved magmaets sammensetning endret seg til monzonittisk, enten ved differensiasjon eller assimilasjon.

Av dette monzonittmagma ble rombeporfyrene dannet. Ved en plutselig bevegelse i jordskorpen ble det igjen dannet en spalte ned til det underliggende udifferensierte basaltiske magma. Basalten E_2 ble dannet av oppstrømmende magma, hvoretter igjen tilførselskanalene ble lukket. Det monzonittiske magma forble nesten uforstyrret. På nytt strømmet basalt-magmaet ut på overflaten og dannet tykke basaltlag, E_3. Men denne gang gikk det oppstigende basaltmagmaet delvis gjennom reservoaret av monzonittmagma, slik at dette ble omrørt øverst; derved fikk det en midlere sammensetning. Den neste erupsjon ble således rektangelporfyren RP_{13}.

Dette rumlige bilde av forholdene øverst i magmakamrene i slutten av effusjonsperioden leder over til dypbergartenes problemer. Larvikitten oppfattes som krystallisert rombeporfyrmagma, og det er utvilsomt korrekt. Men med det rumlige bilde av omrøring av forskjellige magmaer skulle en vente atskillig variasjon i larvikittens sammensetning. Det er da også tilfelle.

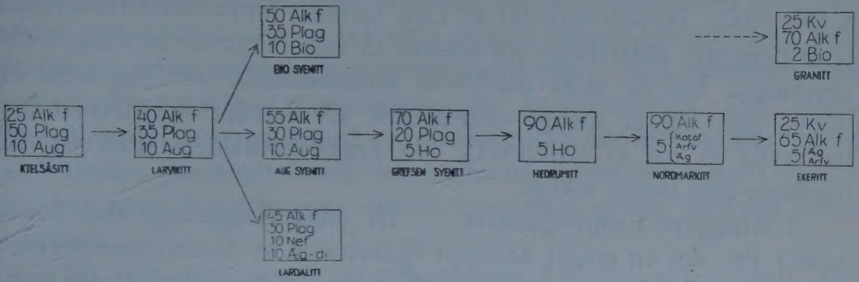

Fig. 1.

I Brøggers fullstendige oversikt over Oslo-bergartene i sin »Typensamlung« fra 1906 er bergartene gruppert i en rekke familier som hver for seg er vel karakteriserbare og tilhører et bestemt tidsintervall i den magmatiske utvikling. Den omfattende analysesamling som Brøgger i 1933 publiserte, viser imidlertid at dypbergartene har jevn overgang fra den ene familie til den annen, og Brøgger brøt litt med sitt tidligere overskjematiserte bilde, idet han oppstilte overgangsserien nordmarkitt-ekeritt. I professor Barths oversikt over dypbergartenes systematiske petrografi (1944) fremgår det at det også er overgangstyper mellom de to viktigste familier, larvikitt og nordmarkitt. I samråd med Egil Sæther har jeg foreslått å dele opp Brøggers nordmarkitt i tre forskjellige bergarter, nemlig nordmarkitt og hedrumitt (nydefinert) for alkalisyenitter med henholdsvis alkalihornblende og alminnelig hornblende som mørke mineraler. En ordinær syenitt med hornblende og litt plagioklas kan da benevnes Grefsen syenitt (Oftedahl, 1948, p. 49).

Ved de siste års feltgeologi og mikroskopering har jeg fått inntrykk av regional utbredelse av overgangsbergarter. Det mest utpregede eksempel er det store massiv som går fra Lågendalen mot Nordagutu (Skrim-massivet). Pyroksengehalten forårsaket at Brøgger benevnte bergarten larvikitt på kartene, mens den på grunn av sin surhet (58 % SiO_2) fikk en egen betegnelse i analysesamlingen: Skrim-typus.

Den systematiske plasering av disse overgangsbergarter er ikke lett, da de to feltspatfaser til dels foreligger som en grov mikroperthitt, og dels i egne krystaller. De viktigste typer i serien kjelsåsitt-ekeritt er vist i ovenstående skjema.

Når nå Brøggers systematikk har vist seg noe skjematisk er det også naturlig å spørre om i hvilken grad Brøggers aldersskjema holder stikk. Hovedresultatet av Egil Sæthers omfattende feltarbeide er at Brøggers aldersfølge fra basiske til sure bergarter er riktig i det vesentlige. For de store massivers vedkommende tror jeg dette er riktig, men det er mange unntagelser for mindre bergartsmasser. Imidlertid er det et hovedtrekk ved eruptivkontaktene som jeg vil fremheve som meget viktig.

I Brøggers Eruptivgesteine ... III (das Gangefolge des Laurdalits) fins det en meget detaljert beskrivelse av lardalittens grenseforhold mot larvikitten. Det fremgår herav at begge bergarter fortsettes uforandret inntil den felles grense; der er ingen finkornig grense, ingen apofyser eller kontaktfenomener. Men på grunn av at nefelinbergartene i Langesundsfjorden er klart yngre enn larvikitten og på grunn av gangbergartenes aldersforhold sluttet Brøgger at lardalitten er yngre enn larvikitten, men at aldersforskjellen var så liten at den eldre bergart ikke var avkjølet da den yngre magma ble presset opp. Disse to bergarter er altså geologisk sett nesten samtidige.

Akkurat samme grad av samtidighet må det være mellom larvikitt og det Brøgger kaller kvartsfattig ekeritt, for på to steder i Hvarnes har jeg funnet at grensen er uten grensefenomener. De to bergarter nordmarkitt og kvartsfattig ekeritt har jevn overgang og ingen grense. Disse observasjoner tyder altså på at det er noenlunde samtidighet mellom bergartene fra og med larvikitt til og med sur nordmarkitt. Derimot er det tydelig grensefacies i den typiske ekeritt mot larvikitt både i Efteløt og ved Myklevann. Ekeritten er altså klart yngre.

Grenser mellom tilsynelatende jevnaldrende bergarter finnes også i Nordmarka. Således er grensen ved Voksen mellom nordmarkitt og akeritt en sprekk uten noen andre grensefenomener enn noen steder antydning til en 2 mm bred, mørkere yttersone i akeritten. Denne kunne da være ubetydelig yngre.

En får herved et nytt bilde av aldersfølgen. Bergartene faller i følgende grupper med noenlunde samtidighet innen hver gruppe:

1. Oslo-essexitt og effusiver.
2. De intermediære dyperuptiver (larvikitt — sur nordmarkitt).
3. Ekeritt.
4. Granitt.

Det er imidlertid mulig at denne inndeling bare gjelder for Vestfold og at dyperuptivene har en litt annen gruppering i Nordmarka og på Hadeland.

I Oslo-feltet finnes også en rekke dypbergartsmassiver med forskjellige bergarter som en må anta tilhører samme periode, i og med at der er jevne overganger mellom bergartene. Som eksempler kan nevnes Finnemarkas granittmassiv og Sandemassivet. Det første massiv består av granitt med en randsone som blir mer og mer basisk mot kanten; det annet massiv har en basisk kjerne (kjelsåsitt) og går gradvis over i randsonens ekeritt. Jeg skal straks beskrive disse nærmere.

Til slutt skal nevnes at aldersfølgen basisk → sur bergart ikke gjelder strengt ved gjentatte intrusjoner. De intrusjoner som forekommer i Glitrevannskalderaen har således følgende aldersfølge:

1. Kvartsporfyr — ringgang, mylonittisert, dannet ved kalderaens innsynkning.
2. Syenittiske sentrale og marginale intrusjoner dannet etter innsynkningen.
3. Det sentrale kvartsporfyr-aplittmassiv, yngre enn de syenittiske intrusjoner.

Vi skal så behandle bergartenes genesis. Jeg har sett så mange feltgeologiske indisier på at Oslo-bergartene er eruptiver størknet av et magma at jeg går ut fra at dette er den generelle dannelsesmåte. Ut fra antagelsen om et basaltisk modermagma blir problemet om de assurere magmaers dannelse atter problemet »differensiasjon eller assimilasjon , — i våre dager som i Brøggers dager. Det er meget vanskelig å finne geologiske indisier på differensiasjon, og det blir derfor, foruten vår generelle geologiske viten, de feltgeologiske iakttagelser over assimilasjon som kaster lys over problemet.

Brøgger mente å finne at inneslutninger i Oslo-bergartene hadde skarp grense, og det samme hadde dyperuptivenes sidebergarter. Han sluttet derfor at assimilasjon ikke forekom i Oslo-feltet, og han utviklet som en av de første geologer i verden teorien om at dyperuptivenes aldersfølge fra basisk til sur kan bero på hovedmineralenes krystallisasjonsfølge.

Det er utvilsomt riktig at dyperuptivene vanligvis ikke viser assimilasjon in situ, men det forekommer. Det peneste eksempel jeg har sett er kontakten mellom granitt og afyrisk basalt, NV for Drammen. Her er det en overgangssone på 3—10 m med hybrider. Hybridene er til dels granitt av modifisert sammensetning med »spökliga rester«, og delvis stripete bergarter av sterkt vekslende sammensetning med diffus overgang mellom mørke og lyse striper. En blotning på et par m² besto av nesten assimilerte bruddstykker hvori satt knoller av basisk plagioklas (55 An), opptil 4 cm store. Dette er et sjeldent eksempel på krystalloblastese ved kontaktmetamorphose. Flere morsomme eksempler på kontaktoppsmeltning er funnet i Glitrevannskalderaen, idet felsittporfyr nær kontakten mot basalt hadde smeltet opp denne, dog uten å blande seg med den, slik at grensesonen består av en bergart med tynne svarte og røde striper av henholdsvis basisk og intermediær sammensetning.

Storstilet assimilasjon forekommer også i Oslo-feltet. Som påpekt av Sæther (1945, p. 431) er akeritten i Vettakollen en tydelig hybrid bergart. Hybrid nordmarkitt forekommer f. eks. i strøket Tryvann-Skjennungen. Også i den søndre del av Siljan kan nordmarkitten være sterkt heterogen, vekslende fra aplittisk til pegmatittisk, med assimilasjonsrester.

Det er imidlertid særlig de sonarbyggede dypbergartsmassiver som er interessante, idet dens dannelse vanskelig kan tenkes uten en eller annen assimilasjonsprosess. Jeg skal først omtale Sandemassivet.

Hele sentrum av Sande-kalderaen består av et massiv som i følge kartene består av noe kjelsåsitt, larvikitt og pulaskitt i midten, utenom en ring av nordmarkitt, og så en kant av ekeritt. Når en imidlertid går fra syd inn til sentrum i massivet synes bergartene å forandre seg jevnt fra ekeritt til kjelsåsitt. I den nordlige halvdel er imidlertid assimilasjonsfenomenene tydelige. Ekeritten synes å være en homogen, primær bergart. Den går over i en syenittisk bergart ved at kvartsinnholdet avtar. I hele den syenittiske sone finnes det bruddstykker av lavaer, med skarpe grenser ytterst, mer diffuse innover. På overgangen til larvikittfeltet er det tydelig at bruddstykkene holder på å forsvinne. Hodestore stykker kan en ennå se omriss av, de mindre er assimilert. Bare en mer jevn, finkornig fordeling av de mørke mineraler enn vanlig antyder mindre bruddstykkers plass. Den basiske bergart i sentrum er for det meste helt homogen.

Disse forhold gjør det naturlig å anta at ekeritten har trengt opp ved stoping, assimilert bruddstykkene fullstendig i midten og bare delvis lenger ute. En komplisert intrusjonsmekanikk må imidlertid antas for å forklare denne »inverse sonarbygning« med maksimal assimilasjon i midten. Et normalt tilfelle av marginal assimilasjon synes vi derimot å ha i randen av det store granittmassiv i Finnemarka, idet vi her har bergarter som blir mer og mer basiske mot yttergrensen.

Ved å gå opp profiler fra kanten og inn til granitten har jeg funnet jevn overgang mellom typene, men noen markert sone med hybrider finnes ikke. Bare enkelte steder er det tett med diffuse inneslutninger, da særlig i den syenittiske sone. I vest var det til dels også skarp grense mellom lysere og mørkere varieteter. Jeg synes imidlertid at feltiakttagelsene tillater en foreløpig å anta at Finnemarkas basiske randsone er dannet ved at granittmagmaet har assimilert sidebergart i økende grad mot grensen. En bekreftelse på dette har vi i den av Barth (1944, p. 69) beskrevne hovlanditt hvor assosiasjonen bytownitt — natronrik alkalifeltspat tyder på at bergarten er en hybrid.

Ut fra Brøggers analysesamling har man en god oversikt over bergartene i assimilasjonssonene. Det er da naturlig å undersøke om de antatte hybrider kan tenkes dannet ved enkel assimilasjon, altså ved blanding av ekeritt med basalt, rombeporfyr, kalk eller leirskifer i forskjellige forhold. Enkel regning viser da at selv om en blander de nevnte bergarter i hvilke som helst forhold, så får en resultater som ikke stemmer overens med naturen for en eller flere viktige komponenters vedkommende. Som enkelt eksempel kan vi betrakte modumitt, en nesten ren bytownittfels. Den kunne tenkes oppstått ved at granitten assimilerer kalkstein. Men da er det særlig den høye aluminiumsgehalt som er uforklarlig.

Assimilasjonsprosessen må altså være ledsaget av andre prosesser av metasomatisk art. Nettopp slike prosesser er i de siste år blitt utforsket særlig av Doris L. Reynolds. Hovedresultatet er det at foran en migmatittfront, eller utenfor granittiseringsfeltet av en granittpluton danner det seg en basisk front. De basiske komponenter Fe og Mg, ofte ledsaget av alkalier, drives vekk i den sone som granittiseres, og de anrikes derved i en utenforliggende sone som derved kan få en basisk eller til og med ultrabasisk sammensetning.

Denne teori lar seg ikke lett anvende på Oslo-feltets hybrider, for de er ikke bergarter særlig anriket på mørke mineraler, noe som er vanlig i den basiske front, men spesielt anriket på feltspat, særlig sur plagioklas og Na-rik alkalifeltspat. Det er mulig at forklaringen kan ligge i at bruddstykkene før de assimileres av granitt, mister en stor del av sitt Fe og Mg etc. til en utenforliggende basisk front, mens alkalier, Ca og H blir tilbake og modifiserer granitten til de feltspatrike syenitt- og monzonittbergarter som er de vanlige (nordmarkitt, akeritt, larvikitt). Det er imidlertid nødvendig å foreta omfattende petrografiske studier for å avgjøre om en såpass spesiell prosess generelt skulle kunne forklare dannelsen av de feltspatrike hybrider som er så vidt utbredt i Oslo-feltet.

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LØKKENFELTETS GEOLOGI

AV

C. W. CARSTENS†

Foredrag i Norsk geologisk forening 7. desember 1949.

Foredraget var ledsaget av et geologisk kart over Løkkenfeltet i målestokk 1 : 50 000 og et geologisk kart over Melhus i målestokk 1 : 100 000, samt tallrike lysbilder.

Da jeg for vel 30 år siden begynte mine undersøkelser av Trondhjemsfeltets kisforekomster viste det seg snart at det på grunn av det virvar som dengang hersket med hensyn til feltets stratigrafiske oppbygning var umulig å få innordnet kisforekomstene i noe som helst brukbart geologisk system. Jeg besluttet meg derfor til i noen år å bryte overtvert med malmgeologien og forsøke å skaffe meg en selvstendig oppfatning av Trondhjemsfeltets stratigrafi.

Den offisielle norske oppfatning på den tid var det system, som ble fremlagt i 1912 av Carl Bugge:

	1.	*Gulagruppen,* øverst.
Midlere gruppe, på Rennebubladet benevnt Støren—Hovingruppen.	2.	*Størengruppen* (med variolit). *Høilandsgruppen* med jaspiskgl. i det hengende og med fossiler fra etasje 5 b. *Hovingruppen* med fossiler fra etasje 5 a (og 4).
	3.	*Rørosgruppen.*

Dette lagsystem var allerede langt tidligere i store trekk lansert av Th. Kjerulf og hans medarbeidere.

Men allerede i 1892 hadde den svenske geolog Törnebohm satt opp et annet lagsystem for Trondhjemsfeltet, som var omtrent rake motsetningen til det norske lagsystem. I Törnebohms hovedarbeide »Grunddragen af det centrala Skandinaviens bergbyggnad«, som utkom 4 år senere, er det vestre Trondhjemsfelts stratigrafi utformet på følgende måte:

Ekne-gruppen.
Høilandets gruppe.
Hovin-gruppen.
Stokvola-breccia (eller kgl.)
Støren-gruppen.
Brekskiffer-gruppen.
Røros skiffergruppe.

Hva var nå riktig?

Jeg ble tidlig klar over at nøkkelen til Trondhjemsfeltets stratigrafi måtte ligge på Melhusbladet. Og for å lære Trondhjemsfeltets bergarter og lagfølge å kjenne kartla jeg i begynnelsen av 20-årene med støtte fra N. G. U. Melhusbladet geologisk — uten tanke på offentliggjørelse, da enkelte bergarter, som ikke hadde betydning for stratigrafien, bare ble skjematisk antydet. Jeg har kartet her i uforandret skikkelse. Over 27 år er gått siden det ble ferdig. Med mitt nåværende kjennskap til feltets geologi er det enkelte ting jeg kunne ønsket anderledes. Men stort sett mener jeg det er riktig.

Det var særlig tolkningen av Guldalsprofilet fra Bymarken i nord til litt sønnenfor Støren i syd, som var av betydning for forståelsen av feltets stratigrafi. Kjerulf, Brøgger og Bugge tolket her Horgområdet mellom Lundemo og Hovin som en saddel (antiklinal), mens Törnebohm oppfattet Horg som en mulde (synklinal). Følgen var, at Hovin-Høylandsgruppene, som etter den norske oppfatning var eldre enn Størengruppen, hos Törnebohm ble yngre.

Etter inngående undersøkelser kom jeg i 1920 til samme oppfatning som Törnebohm. Jeg skriver således i »Oversigt over Trondhjemsfeltets bergbygning« side 33: »Da Törnebohms Brekskiffergruppe tildels omfatter Rørosgruppens høiere horisonter dekker det reviderte lagsystem (opsatt av mig) temmelig nøiaktig Törnebohms systems vestlige facies. Det omfatter følgende grupper:

Hovingruppen (inkl. Høilands- og Ekneavdelingene).
Bymarkgruppen.
Rørosgruppen.«

Til denne inndeling har senere også Thorolf Vogt sluttet seg (1945).

Lagfølgen mellom Orkedalsfjorden i vest og Trondhjems Bymark i øst er meget enkel. Her ligger grønnsteinsformasjonen, som jeg har kalt Bymarkgruppen, direkte over Rørosgruppen, og i Guldalsprofilet dukker Bymarkgruppen atter opp ved Støren på muldens sydside. Da utgangspunktet i Guldalsprofilet er Trondhjems Bymark er det naturlig å benytte navnet Bymarkgruppen for grønnsteinsformasjonen, så meget mer som Størengruppen er benyttet dels som navn på en gruppe eldre enn Hovingruppen, dels som navn på en gruppe yngre enn Hovingruppen.

På basis av de geologisk-stratigrafiske undersøkelser i marken syntes å fremgå, at Høylandets skifre og kalksteiner — liksom Kalstadkalken — var eldre enn sedimentene i Sandåmulden (Hovingruppen i engere betydning). Men etter de paleontologiske arbeider av Brøgger (1875) og Kiær (1905) fremgikk, at Høylandsgruppen var yngre enn Hovingruppen. Feltgeologen kom derved i en meget vanskelig stilling — et sted måtte det øyensynlig være en feil. Først da Kiærs store arbeide »The Hovin group in the Trondheim Area« ble offentliggjort i 1932, ble forholdene klare. På basis av reviderte fossilbestemmelser henføres i dette arbeide Høylandsgruppen (eller Høylandsavdelingen) til Hovingruppens laveste horisonter. Den lagfølge, som hele tiden hadde fremgått av de geologisk-stratigrafiske undersøkelser, fikk derved til slutt sin paleontologiske bekreftelse.

Hovingruppen kan således inndeles på følgende måte:

Øvre Hovingruppe (yngst).
Midtre Hovingruppe.
Høylandsavdelingen (eldst).

Etterat denne inndeling ble klarlagt har samtlige formasjonsledd — iallfall i den vestre del av Trondhjemsfeltet — uten vanskelighet kunnet tilpasses det reviderte lagsystem.

Løkkenfeltet kaller vi i daglig tale den del av Trondhjemsfeltet, som ligger mellom Malberget på Hølonda i øst og Lommunda—Tifjell i vest, mellom Svorkmo i nord og Grindal i syd. Arealet er ca. 600 km². Over dette felt ble der i 1937 opptatt flyfotografier av Widerøes Flyveselskap A/S, Oslo, i målestokk omkring 1 : 15 000. Forøvrig foreligger bare eldre og meget unøyaktige topografiske karter i målestokk 1 : 100 000 og 1 : 50 000.

Med henblikk på videregående malmgeologiske undersøkelser i forbindelse med malmleting ble der i 1937 påbegynt en geologisk detaljkartlegging av hele Løkkenfeltet. Arbeidet gikk imidlertid temmelig langsomt, til dels av den grunn at geologen i begynnelsen stadig måtte være til stede ved de geofysiske målinger, som i alle år — unntatt i krigens år — er utført av Geofysisk Malmleting, Trondhjem, i årene 1938 og 1939 også av A/B Elektrisk Malmleting, Stockholm. I årene 1940—1946 hvilte alt arbeid i Løkkenfeltet. Først i 1947 gikk vi igjen i gang for alvor.

Ved alt geologisk kartleggingsarbeid er nyttet flyfotografier. Flykartene er senere overført til de mindre gode topografiske karter, hvorved unøyaktigheter mange ganger ikke var til å unngå. Men når nye topografiske karter engang i fremtiden vil foreligge, vil man på basis av flykartene kunne få et helt nøyaktig geologisk kart.

Jeg har i de år jeg har arbeidet i Løkkenfeltet hatt hjelp av atskillige assistenter, fortrinsvis berg- og realstuderende, særlig til fastlegging av bergartsgrenser. Jeg bringer alle disse min aller beste takk. Men feltet er i mange henseender vanskelig, spesielt er det ofte nesten umulig å atskille Hovingruppens grønne sandsteiner fra Bymargruppens grønnsteiner. Og de eruptive felsiter kan i svært mange tilfelle ikke atskilles fra de sedimentære felsiter. En rekke forskjellige lokaliteter er derfor besøkt både 3 og 4 ganger. Og ofte flere ganger samme år. Det er hovedsakelig grunnen til at jeg har holdt offentliggjørelsen av kartet tilbake helt til i høst. Kartet vil bli trykt neste år og publisert i den jubileumsboken som kommer ut i 1952 i anledning Løkken gruves 300-års jubileum.

Løkkenfeltet danner — slik som det også fremgår av kartet — en mulde eller et traug med muldeakse E—W, begrenset både i nord og syd av Rørosgruppen. Over Rørosgruppen (og yngre enn denne) ligger Bymarkgruppen, i nord med dels normal, dels invertert lagstilling, i syd overalt med normal (N-lig) lagstilling. I muldens sentralparti ligger feltets yngste gruppe Hovingruppen, på de fleste steder atskilt fra den underliggende Bymarkgruppen ved det fra Trondhjemsfeltet meget kjente jaspiskonglomerat, av Törnbohm kalt Stokvolakonglomerat.

På grunn av den sterke folding dukker Bymarkgruppen enkelte steder i østfeltet ryggformet opp innenfor Hovingruppens områder, således i Malberget, i Grønlifjellet og i Grefstadfjellet. Derved fremkommer 3 tydelig utviklede Hovingruppemulder, den ene vest for Svorksjøen, den andre syd for Høydalskammen, den tredje øst for Frilsjøen.

I vestfeltet er Hovingruppen atskillige steder helt innfoldet i Bymarkgruppen. Det største av disse innfoldete partier ligger omkring

Blåbærhaugen og fremtrer her som en vestlig fortsettelse av Friljømulden.

Strøket i Løkkenfeltet er for den helt overveiende del omkring E—W. Fallet er omtrent overalt, unntatt i den aller nordligste del og i området N Ilfjellet, steilt til middelssteilt N-lig. Langs nordgrensen, i og omkring den derværende Rørosgruppe, er fallet sterkt vekslende, overveiende S-lig. Foldningsaksen har i den vestlige del av feltet svakt E-lig fall og i midtre del av feltet, omkring Løkken, svakt W-lig fall, ca. 15°. Foldningsaksens kulminasjon ligger straks øst for Løkken, slik at aksefallet i feltets østre del atter er svakt E-lig.

De fleste kontakter er primærkontakter, forskyvninger (glidninger) synes bare å ha funnet sted i underordnet grad. Men forkastninger av betydelig størrelsesorden opptrer flere steder.

Rørosgruppen, som flankerer Løkkenfeltet i nord og syd, har jeg ikke studert særlig inngående unntatt kontaktene langs Bymarkgruppen. På nordsiden fører gruppens øvre horisonter overveiende grå og brune glimmerskifre, til dels med porfyroblastisk utviklet feltspat, hornblende eller biotit, grå sandsteinsskifre og — i alminnelighet nærmest Bymarkgruppen — gråblå fylliter og kalksteinsbergarter (marmorisert), til dels svarende til Törnebohms Brekkskifergruppe.

Liksom de fleste steder omkring Trondhjem er der på nordsiden av Løkkenfeltet ikke noen skarp grense mellom Rørosgruppen og Bymarkgruppen. Således finner vi overalt i Rørosgruppens øverste horisonter innlagret grønnsteinsbenker av samme karakter som grønnsteinene i Bymarkgruppen. Det er til en viss grad en smaksak hvor man setter grensen mellom de 2 grupper, ved første grønnsteinsbenk eller ved siste glimmerskifer- eller fyllitlag. Personlig har jeg i regelen satt grensen ved første grønnsteinsbenk.

I Løkkenfeltets østre del er Rørosgruppens høyere horisonter på nordsiden gjennomsatt av en rekke ganger av feltspat- og hornblendeporfyrit av samme karakter som Hølondaporfyritene. De er bl. a. lett synlig i Trevjas elveleie sydøst for Svorkmo.

På sydsiden av Løkkenfeltet er Rørosgruppens øvre horisonter stort sett enklere oppbygget enn på nordsiden. Gråbrune glimmerskifre, som særlig i feltets vestre del er gjennomsatt av tallrike ganger av hvit granit og amfibolit, er de alminneligste bergarter.

Den interessanteste gruppe i Løkkenfeltet er *Bymarkgruppen,* som for den helt overveiende del er oppbygget av (submarine) grønnsteinslavaer av andesitisk-basaltisk sammensetning. Grønnsteinene er i metamorf henseende utviklet i grønnskiferfacies opp til epidot-amfibolit-facies — de er dels skifret, dels masseformet og i så fall meget ofte utviklet som putelava. Grønnsteinene og grønnsteinsskifrene er imidlertid meget interessante bergarter — de fortjener utvilsomt et helaftens foredrag alene. De er tidligere omtalt mer kortfattet av flere forskere, av Carl Bugge, Goldschmidt, Thorolf Vogt, meg selv og andre. Men noen inngående beskrivelse er aldri blitt den tildel fra norsk side. Tiden tillater dessverre heller ikke i aften å gå nærmere inn på grønnsteinene og deres forskjellige derivater. Jeg vil bare få nevne — siden jeg tror det er mindre kjent — at grunnmassen eller mellommassen i putelavaene flere steder delvis er utviklet som røde skifre, altså som sedimenter. Dette forhold er imidlertid et vel kjent fenomen fra andre kanter på jorden, hvor putelava er kommet til utvikling. Volney Lewis har således allerede i 1914 fra flere områder beskrevet putelavaer med så vel tuffitisk som sedimentær mellommasse (i Bull. of the Geol. Society of America, Vol. XV). Men i alminnelighet er mellommassen i Løkkenfeltets putelavaer av tilnærmet samme sammensetning som putene. Muligens er mellommassen i enkelte tilfelle primært utviklet som glass, slik som forholdet er i putelavaene i det böhmiske grunnfjell, omtalt i 1926 av F. Slavik (i Congres Geologique Interational, Comptes Rendus de la XIV^e^ Session, 1926).

Mens de mer kompakte (masseformete) grønnsteiner, dels med ordinær struktur, dels i form av putelava, i alminnelighet representerer (submarine) lavastrømmer, er grønnsteinsskifrene i de fleste tilfelle sedimenter (grønnsteinsderivater) eller tuffer. Men atskillige steder representerer grønnsteinskifrene med sikkerhet også sterkt forskifrete lavastrømmer.

Andre sedimenter enn grønnsteinsskifrene opptrer forholdsvis underordnet i Bymarkgruppen. Vi har jaspislag, i hvis selskap de kjente vasskislag eller Leksdalskiser meget ofte forekommer, enn videre kvartsiter, sparagmiter (i alminnelighet utviklet som såkalte sedimentære felsiter eller hårdskifre), kalksteiner, i alminnelighet marmorisert, og grafitskifre.

Svakt metamorforserte leirskifre og sandsteinsbergarter av den karakter som Vogt i sitt arbeid over Hølonda—Horg-distriktet har benevnt »Jåren-beds« har jeg ingen steder iakttatt som innleiringer i Bymarkgruppen, hverken i Løkkenfeltet eller på Melhusbladet. Og da »Jåren-beds« i vest — i Klefstadåsen — direkte hviler på jaspiskonglomeratet (Stokvolakonglomeratet), som forøvrig ikke er inntegnet på Vogts kart, antar jeg derfor, at Vogts »Jåren-beds« temmelig sikkert er Hovingruppebergarter, og at disse lag med god samvittighet kan strykes som en avdeling av Bymarkgruppen.

Jeg kan forøvrig tilføye at de såkalte »Jåren-beds« vest for Gilhaugen allerede på Törnebohms kart av 1896 er henført til Hovingruppen. Endog grønnsteinsryggen fra sydenden av Anøyen til Gilhaugen er delvis kommet med på Törnebohms kart.

Det beste profil gjennom Bymarkgruppen har vi langs jernbanelinjen og riksveien mellom Svorkmo og Haugen gård, litt sønnenfor Løkken, over en strekning av vel 5 km. De nordligste horisonter er her for en meget vesentlig del utviklet som grønnsteinsskifre. Men den overveiende del av profilet viser masseformet grønnstein, flere steder utviklet som putelava. Omtrent midt i profilet opptrer vasskislagene ved Skjødskift (nordligst) og Jordhus (sydligst).

Putelavaen, som innenfor hele Bymarkgruppen er en meget alminnelig bergartstype, finnes imidlertid aldri i gruppens laveste horisonter. Disse er overalt — så vel i nord som i syd — utviklet som grønnsteinsskifre. Putelavaen er derimot meget vakkert utviklet i gruppens midtre og øvre horisonter, jeg nevner i fleng Høydalskammen, Grefstadfjellet, Einarshammeren og Tifjellet.

Til Bymarkgruppen må også henføres den bergart, som jeg under feltarbeidet har kalt felsit, fordi den i alminnelighet har et helt felsitisk utseende. Leilighetsvis er strukturen også porfyrisk med tett felsitisk grunnmasse.

Felsiten har ingen steder noen større arealutbredelse. Den opptrer i de fleste tilfelle linseformet, vanligvis av størrelsesorden noen tusen m² opp til omkring ½ km². I terrenget viser den seg meget ofte kuppe-formet, da den på grunn av hårdhet og seighet motstår erosjonen langt bedre enn den omgivende grønnsteinsbergart. Jeg nevner i denne forbindelse »Kongen« og felsitkuppene vestenfor Halsgjerdet.

Felsitenes mineralselskap er meget enkelt. Sur plagioklas og leilighetsvis underordnet kvarts er de alminneligste innsprengningsmineraler i en tett, lys, ofte nesten ubestemmelig grunnmasse, bestående fortrinsvis av sur plagioklas. Sericit, epidot og klorit opptrer alltid i helt ubetydelige mengder.

Analyser av prøver fra »Kongen«, Dalatjern, »Hesteskoen« og Wallenberg viser følgende sammensetning:

	I »Kongen«	II Dalatjern	III »Hesteskoen«	IV Wallenberg
SiO_2	64,16	75,33		
TiO_2		0,30		
Al_2O_3		12,09		
Fe_2O_3		0,64		
FeO		1,08		
MnO		0,04		
MgO	0,06	0,76		
CaO	0,54	1,20		
Na_2O	9,02	4,12	4,75	4,78
K_2O	1,17	2,26	1,43	1,37
CO_2		0,70		
P_2O_5		0,07		
H_2O+		0,93		
$H_2O\div$		0,08		
		99,52		

I er analysert av B. Bruun (ikke ferdig analysert), II av Naima Sahlbom (gammel analyse), III og IV av Orkla Grube A/B.s laboratorium, Løkken Verk.

Av analysene fremgår at felsitene — iallfall delvis — i kjemisk henseende står temmelig nær trondhjemitene. Felsitmagmaet har således på sin vandring opp gjennom den øvre del av jordskorpen med sikkerhet vært overordentlig viskost. Derav følger — i de tilfelle det har nådd opp i dagen — den helt ubetydelige arealutbredelse. Det synes helst å ville størkne i form av necks (vulkanpropper) eller i form av ganske korte lavastrømmer. Når felsitmagmaet ikke har nådd opp i dagen har det undertiden også størknet i form av ganger med som regel temmelig kort feltutstrekning.

Jeg antar at det gamle navn kvartskeratofyr best dekker betegnelsen på effusiver av felsitenes karakter. Dette navn er også benyttet av Vogt på intrusivganger av liknende utseende og liknende sammensetning på Hølonda.

Vogt har imidlertid på sitt kart over Hølonda ikke inntegnet effusive felsiter innenfor Bymarkgruppens områder. Men i Kvithyllås opptrer som navnet sier, en hvit bergart, lett synlig fra veien. Det er øyensynlig en hvit felsit med innsprengninger av sur plagioklas og en del kvarts i en meget finkornet grunnmasse, noenlunde lik flere av Løkkenfeltets felsiter. Den opptrer, som disse, linseformet i Bymarkgruppen, men den har på grunn av innsprengningsmineralenes størrelse og mengde makroskopisk mer likhet med en granit. På mitt Melhusblad er den derfor også kalt hvit granit.

Stratigrafisk avsluttes Bymarkgruppen oppad av det meget kjente jaspiskonglomerat, som fører boller av forskjellig slags bergarter, felsit, grønnstein, kalkstein (hvit marmor), rød skifer, jaspis m. m. i en grønnsteinsskifergrunnmasse, med andre ord: boller av bergarter, som alle finnes i grønnsteinsformasjonen. Dette konglomerat må betraktes som et basalkonglomerat for den overliggende formasjonsgruppe, Hovingruppen. Det skulle på kartet av den grunn kanskje helst være tegnet med violett farge. Men når blotningene er dårlige og når antallet av boller er sparsomt, er det i marken ofte meget vanskelig å atskille fra den ordinære grønnstein. Jeg har derfor på kartet — på de steder, hvor det er iakttatt — betegnet jaspiskonglomeratet med røde prikker på Bymarkgruppens grønne bunnfarge. Som det vil sees av kartet, er det synbart på en rekke forskjellige steder på grensen mellom Bymarkgruppen og Hovingruppen. Og antagelig er det utviklet i svakere grad på de fleste steder langs ovennevnte grense.

Betegner man jaspiskonglomeratet — slik som Vogt har gjort på sitt Hølondakart — med egen farge, får man lett det feilaktige inntrykk, at det bare finnes hist og her. Mens forholdet i virkeligheten er, at det er umåtelig konstant.

Jeg setter derfor Bymarkgruppen med grønn farge og anfører: i sine øverste horisonter (på grensen mot Hovingruppen) i alminnelighet utviklet som jaspiskonglomerat. Og på de steder, hvor konglomerater er iakttatt, setter jeg røde prikker. På den måte blir kartet — på dette meget viktige punkt — uangripelig.

Jeg kan også nevne at den eneste, som foruten Vogt har anført jaspiskonglomeratet på sine karter, er Törnebohm, som har undersøkt det på hele strekningen mellom Levanger i nordøst og Meldal i sydvest, over en lengde av over 10 norske mil i luftlinje (når man bortser fra Brøggers lille kartskisse fra 1878). Og Törnebohm har benyttet en liknende betegnelse — krysstreker på Størengruppens grønne bunnfarge — sikkert som en dyd av nødvendighet.

Jaspiskonglomeratet opptrer atskillige steder i veksellagring med rød skifer (eller rød sandstein), et forhold som jeg har iakttatt så vel på Melhusbladet som i Løkkenfeltet. Og leilighetsvis synes den røde skifer helt eller delvis å erstatte konglomeratet. Undertiden opptrer også marmorlag som innlagringer.

Et karakteristisk trekk ved jaspiskonglomeratet er den sterke veksellagring mellom bollerike og bollefattige til nesten bollefrie lag (tydelig utviklet ved Svorksjøen) i forbindelse med sterk veksling av storbollet og finbollet, avrundet og kantet materiale. De bollefrie lag, som petrografisk får karakteren av grønnsteinsskifre, kan i marken ofte vanskelig atskilles fra forskifrede lavabenker. Men de viser under mikroskopet vanligvis uren kalksandsteinssammensetning.

Atskillige steder, således bl. a. nord for Storbuan, opptrer imidlertid også normale grønnsteinsbenker (med eruptiv struktur), som innlagringer i jaspiskonglomeratet. Disse benker kan neppe fortolkes som innpressete flak av den underliggende grønnsteinsformasjon eller som gjennomsettende gangbergarter. De synes med sikkerhet å representere normale lavastrømmer, fremkommet under jaspiskonglomeratets dannelse.

Dette eiendommelige forhold har jeg også iakttatt flere steder utenfor Løkkenfeltet, så vel på Melhusbladet som på Trondhjemsbladet. Det står således omtalt allerede i mitt arbeide fra 1920. Særlig i Strøket Bratsberg—Ler opptrer tydelig utviklede grønnsteinsbenker med masseformet struktur og effusiv karakter som mellomlag i det derværende jaspiskonglomerat.

Jaspiskonglomeratet har av Törnebohm, som er den første som har gitt en utførlig beskrivelse av det over hele dets utstrekning mellom Levanger i nord og Meldalen i syd, fått navnet Stokvolakonglomerat (eller breksje) etter fjellet Stokvola i Åsen, hvor det er særlig karakteristisk utviklet. Det bør antagelig for ettertiden få beholde dette navn. Personlig har jeg kalt det dels grønnsteinskonglomerat, dels jaspiskonglomerat. Det sistnevnte navn er et godt og karakteristisk navn i marken, da konglomeratet i de fleste tilfelle (men dog slett ikke alltid) fører boller eller bruddstykker av jaspis, som — på grunn av sin røde farge — er lett synlig mot den grønne grunnmasse. Vogt har i sitt Hølondaarbeide benyttet Vennakonglomerat (eller Gaustadbakkbreksje) som navn på jaspiskonglomeratet, da det bl. a. steder er anstående like ved Ven gård. Men Vogts navn er etter min mening dårlig. Konglomeratet sees her bare over et ganske lite område uten særlig karakteristisk utvikling, vesentlig i stranden under vannspeilet.

Bymarkgruppens mektighet er sterkt varierende på de forskjellige steder. Den er således omkring 0 m (utkilt) ved Bøverdalshaugen (øst for Svorkmo), hvor jaspiskonglomeratet ligger omtrent umiddelbart på Rørosgruppens øverste horisonter, og omkring et par hundre meter i sydvest omkring Reisvannet. Men på grunn av sterke foldninger er en nøyaktig angivelse av mektigheten i alminnelighet meget vanskelig. Således viser grønnsteinssadlen (grønnsteinsryggen eksklusive jaspiskonglomeratet) på Grønlifjellet et isoklinalt, middelssteilt fall over en horisontalbredde av omkring 800 m. Derav følger, at grønnsteinen (eller Bymarkgruppen) her antagelig har en maks. mektighet på ca. 400 m. Lengre syd — i Grefstadfjellet — er imidlertid mektigheten etter all sannsynlighet betydelig større.

Jaspiskonglomeratets mektighet er likeledes sterkt varierende, fra omkring ½ m (såvidt merkbart) opp til flere hundre meter. Innenfor Løkkenfeltet er det vakrest utviklet på Høydalskammen og omkring Svorksjøen.

Stratigrafisk over jaspiskonglomeratet, som overalt, hvor det finnes, betegner en betydelig diskordans, ligger *Hovingruppens* forskjellige bergarter, kalksteiner, leirskifre, sandsteiner og konglomerater. Gjennomgående er disse bergarter langt svakere metamorfosert enn Rørosgruppens og Bymarkgruppens bergarter. Og aller svakest er metamorfosen på Hølonda med de mange fossilfunn.

Alle forskere som har arbeidet i Trondhjemsfeltet, har siden Törnebohms dager vært oppmerksom på denne diskordans. Også Carl Bugge, skjønt han ikke har inntegnet jaspiskonglomeratet på sitt kart Rennebu. Men han sier i beskrivelsen til kartet, at dette konglomerat bør benyttes som skille mellom Støren- og Hovingruppen. Her må vi imidlertid være oppmerksomme på at etter Bugges oppfatning var den gamle Størengruppe (som jeg kaller Bymarkgruppen) *yngre* enn jaspiskonglomeratet og Hovingruppen.

Den fjellkjedefoldning (landhevning og metamorfose) som således etter all sannsynlighet har funnet sted førenn jaspiskonglomeratets dannelse, har av Holtedahl fått navnet »the Trondheim disturbance«. På norsk kan den vel kalles trondhjemsfasen eller »den trondhjemske fjellkjedefoldning«.

Jeg har på kartet ikke foretatt noen detaljert inndeling av Hovingruppens bergarter. Tiden har dessverre ikke strukket til. Dertil kommer, at på et kart, hvis hovedoppgave er å være et hjelpemiddel for den geofysiske malmleting, har en videregående inndeling av

Hovingruppen ingen hensikt. All malm i Løkkenfeltet — det gjelder så vel kobberholdige gangkiser (av typus Løkken og av typus Jorfjell) som kobberfrie vasskiser (av typus Leksdalen) — opptrer nemlig stratigrafisk *under* jaspiskonglomeratet. Vi sier derfor at Hovingruppen er malmgenetisk steril.

Jeg har imidlertid likevel ofret relativt meget tid på undersøkelser innenfor Hovingruppens områder. For Hovingruppen byr på svært meget av generell geologisk interesse.

Et meget interessant forhold er således, at en stor del av de sparagmitisk utviklede bergarter har et fullstendig felsitisk utseende. Det er mange ganger ikke mulig i marken — ofte heller ikke i mikroskop — å atskille disse tilsynelatende sedimentære felsiter fra Bymarkgruppens eruptivfelsiter. Hovingruppens felsiter fører overveiende innsprengninger eller bruddstykker av sur plagioklas og bruddstykker av fremmede bergarter i en forholdsvis tett, ofte litt ujevnt kornet grunnmasse, til dels med lagningsstruktur, og har — i motsetning til eruptivfelsitene — i regelen en meget stor feltutstrekning samtidig som mektigheten er forholdsvis minimal. De veksellagrer stadig med sandsteiner og konglomerater, undertiden også med leirskiferbergarter, altså sikre sedimenter.

Når man betrakter det mikroskopiske bilde av flere av disse felsiter, særlig fra Langvannsåsen, nordøst for Grutsæter, hvor forholdene er mest kompliserte, vil vistnok mange være tilbøyelig til å oppfatte disse bergarter som eruptivbergarter. Og i mange tilfelle lar det seg visstnok heller ikke gjøre — på basis av det mikroskopiske bilde — å komme til et sikkert resultat. »Men man må ikke se på bjerge bare i mikroskop«, som de gamle geologer sa ved innførelsen av mikroskopet i det forrige århundre. Det blir her — som alltid — de geologiske undersøkelser i marken som veier mest.

Men for å vise hvor vanskelig dette spørsmål er, skal jeg få demonstrere et par preparater av grunnmassen i ordinære storbollete polygene konglomerater, som opptrer i veksellagring med typiske sedimentære felsitlag oppe i Langvannsåsen. De mikroskopiske bilder minner i meget sterk grad om eruptiver. Men man kan vel ikke være i tvil om at man her iallfall har bilder av et sediment.

Hovingruppens felsiter er i Løkkenfeltet fortrinsvis utbredt i Smidalen, i strøket Høgknippen—Skittenfjell, i Langvannsåsen og i traktene omkring Syrstad. Og da Høgknippens felsitfelt synes å stryke direkte mot Grimsåsens felsiter som av Vogt er oppfattet som rhyolitiske lavaer, har jeg på nytt — et par dager —studert Grimsåsens felsitfelt.

Det synes meg imidlertid temmelig klart, at alt det som Vogt har betegnet som rhyolit på sitt Hølondakart, umulig kan være en lava. En dagbergart med den sammensetning som Grimsåsfelsiten har, vil i magmatisk tilstand være overordentlig viskos. Den ville antagelig ikke — hvis den eksisterte — under noen omstendighet — kunne ha fått den svære arealutbredelse i forbindelse med den minimale mektighet som er angitt på Vogts kart. Og det viser seg da også ved nærmere undersøkelser, at en stor del av bergartene i Grimsåsen fører større og mindre bruddstykker av fremmede bergarter, dels kantete, dels runde. Disse bergarter er med sikkerhet klastiske, rene sedimenter eller tuffer. Spørsmålet er bare: Finnes der i det hele tatt lavabergarter i Grimsåsen? Og i så fall hvor meget? Eller eksisterer der her bare klastiske bergarter, eventuelt tuffer?

Svaret på dette spørsmål er selvsagt av stor interesse for forståelsen av de geologiske forhold under Hovingruppens dannelsestid i hele det vestre Trondhjemsfelt.

At Grimsåsens felsitfelt — like så vel som Hovingruppens felsitfelter i Løkkenfeltet — ikke er oppbygget av en enkelt homogen bergart men av forskjellige slags bergarter, så vel klastiske bergarter som antagelig også effusiver, fremgår ikke bare av de geologiske undersøkelser i forbindelse med det mikroskopiske preparatstudium, men også av de kjemiske analyser. Jeg gjengir nedenfor en del alkalianalyser av bergarter med forskjellig slags struktur fra Grimsåsen og Langvannsåsen. Til sammenligning har jeg anført Vogts analyse av rhyoliten fra Nordtømme og mine egne analyser av den eruptive felsit (rhyoliten) fra Dalatjern og Wallenberg (i Bymarkgruppen)

	I	II	III	IV	Nordtømme	Dalatjern	Wallenberg
SiO_2 …	69,1	69,2	76,2		73,17	75,33	
Na_2O …	1,48	4,98	4,58	4,62	4,52	4,12	4,78
K_2O …	0,68	2,31	2,38	1,12	3,31	2,26	1,37

I Sikker klastisk bergart (tuff), Grimsåsen.
II Sikker klastisk bergart (tuff), Grimsåsen.
III Muligens lava, Grimsåsen.
IV Muligens lava, Langvannsåsen.
Analysene I—III er utført av F. Heidenreich.
Analyse IV er utført på Orkla Grube A/B.s laboratorium.

Prøvene I—III er alle slått på Grimsåsens søndre avheld nord for Grimstjernet innenfor det på Vogts kart som rhyolit anførte område.

Av ovenstående analyser skiller iallfall analyse I seg sterkt ut fra de øvrige. Denne prøve representerer med sikkerhet en klastisk bergart. Likeså er prøve II sikkert klastisk. Den fører således kantete bruddstykker av kvartsit og feltspatporfyrit, samt splinter av en glassliknende substans i en tett felsitisk grunnmasse. Prøven representerer etter all sannsynlighet en tuff. Derimot er det mulig, at prøve III representerer en lavabergart. Den står således — hva kiselsyre- og alkaligehaltene angår — relativt nær Dalatjernfelsiten. Likeledes er det mulig at prøve IV fra Langvannsåsen representerer en lava. Den står i så fall relativt nær Wallenbergfelsiten.

Konklusjonen av alle disse undersøkelser er i korthet, at Hovingruppens felsitfelter på strekningen mellom Guldalen og Orkedalen til dels er oppbygget av rent klastiske bergarter og av tuffer, sannsynligvis tilblandet i større eller mindre grad rhyolitiske lavastrømmer.

Spørsmålet om hvor meget der finnes av hver enkelt bergartstype innenfor disse felter er av meget stor interesse. Det kan bare besvares etter inngående detaljundersøkelser, fortrinsvis i Grimsåsen og Langvannsåsen.

Hovingruppen er — likesom både Bymarkgruppen og Rørosgruppen — på en rekke steder, særlig i østfeltet, i retning mot Hølonda, gangformig gjennomsatt av plagioklas- og hornblendeporfyriter av vekslende mektighet, leilighetsvis også av finkornete gabbroidale ganger, som både mineralogisk og strukturelt har stor likhet med porfyritenes grunnmasse. Gjennomgående er mektigheten 30—50 m eller deromkring, men går undertiden ned til et par meter eller derunder, f. eks. umiddelbart syd for lille Damvann (som ligger et par km nord for Svorksjøen). Porfyritgangenes lagstilling er i regelen konform skifrigheten.

Porfyritbergartene på Hølonda er av de forskjellige forfattere oppfattet dels som gangbergarter, dels som lavabergarter. Brøgger oppfattet disse bergarter allerede i 1877 som intrusiver. Han skriver derom i »Forhandlinger i Videnskab-Selskabet i Christiania« samme år: »I Nærheden af Eruptiven, navnlig i Kalk, Marmor paa flere Punkter (Trongemyrsaasen, Katugelaasen, Østre Viksaasen, Sundsæt), fandtes større og mindre, Fod og Kvarter, indtil kun et Par Tommer store, fuldstændig isolerede Lindser af Eruptiven, i ingen Henseende forskjellig fra denne. At disse er yngre end Kalken og indtrængte i denne ad nu ikke mere synlige Aabninger, kan ikke være tvivlsomt for den, der ikke tvivler paa, at betreffende Bergart er en Eruptiv.« Törnebohm har derimot oppfattet Hølondas plagioklas- og hornblendeporfyriter som lavaer, det samme har også Vogt gjort. Personlig hadde jeg også den oppfatning i 1920. Men etterat jeg et par år senere fikk anledning til å studere porfyritenes opptreden i Løkkenfeltet, hvor gangkarakteren er mer utvilsom, kom jeg ved fornyede undersøkelser på Hølonda til den slutning, at porfyritene i alminnelighet er ganger og ikke lavaer (Norsk geol. Tidsskrift 1922. Også på Melhusbladet er — som det vil sees — porfyritene inntegnet som ganger, helt skjematisk).

Av dypbergarter gjennomsettes Løkkenfeltet av så vel gabbro som hvit granit, trondhjemit. Av disse bergarter er gabbroen uten tvil den interessanteste, forsåvidt som den oppfattes som moderbergarten for Løkkens kobberholdige gangkiser.

I alt finnes der i Løkkenfeltet 8 til 9 forskjellige gabbrofelter, samtlige innenfor Bymarkgruppens område. Det største av disse er gabbrofeltet Hoslynga—Fagerlivann (Wallenberg), som har en lengdeutstrekning fra vest til øst av ca. 7 km. Det er i liggen av dette gabbrofelts østre utkiling at Løkkenkisen opptrer.

De forskjellige gabbrofelter har tilnærmet samme mineralselskap og kjemiske sammensetning, dog med visse variasjoner. Hoslynga—Fagerlivann-gabbroen fører således basisk plagioklas, delvis epidotisert, og pyroxen, delvis omvandlet til nesten fargeløs hornblende, mens Frilsjøgabbroen fører pyroxen, delvis omvandlet til lysegrønn hornblende i tilsynelatende isotrop grunnmasse, vesentlig sammensatt av klinozoisit, omvandlet av plagioklas.

Analyser av de 2 typer er anført nedenfor:

	Gabbro Fagerlivann	Gabbro Frilsjøen
SiO_2	46,73	47,10
TiO_2	1,53	0,49
Al_2O_3	14,38	18,86
Fe_2O_3	3,35	1,99
FeO	7,99	4,59
MnO	0,18	0,20
MgO	9,39	8,07
CaO	12,41	15,18

	Gabbro Fagerlivann	Gabbro Frilsjøen
Na_2O	2,02	1,97
K_2O	0,32	0,14
P_2O_5	0,14	0,03
CO_2	spor	spor
S	—	—
H_2O+	2,11	1,27
$H_2O\div$	0,05	0,12
	100,60	99,93

Begge analyser er utført av B. Bruun.

Den vesentlige forskjell på disse 2 gabbrotyper i kjemisk henseende er den langt høyere jernoxydoxydulgehalt i type I og den betydelig høyere leirjordgehalt og kalkgehalt i type II.

Begge gabbroanalyser står forholdsvis nær flere av de foreliggende analyser av grønnsteinslava. Kalkgehalten er imidlertid vesentlig høyere i dypbergartene.

I motsetning til gabbro er den hvite granit, trondhjemiten, en sjelden bergart i Løkkenfeltet. Den opptrer bare over strøket Skamfjellet—Jorfjellet langs feltets søndre begrensning. Mineralselskapet er sur plagioklas, delvis omsatt til epidot, og sericit, kvarts og biotit, delvis kloritisert. Strukturen er normalkornet.

Langs granitkontakten er grønnsteinen over en bredde av opp til 50 m eller litt derover amfibolitisert, hvorved fargen i kontaktsonen har slått over fra grønn til svart. Denne kontaktsone er også iakttatt av Carl Bugge og inntegnet på hans Rennebukart. Den synes å gå gradvis over i grønnstein. Men Bugge oppfatter — i motsetning til meg — amfiboliten som en basisk grensefacies av graniten.

I granitens umiddelbare kontaktsone, innlagret i amfibolit, opptrer flere steder, så vel på Jorfjellet som på Skamfjellet kisganger av mektighet opp til 1 à 2 m med overveiende E—W-lig strøkretning og N-lig fall. Mineralselskapet er hovedsakelig svovelkis, en del magnetkis, litt kobberkis samt kvarts.

Vi har således i Løkkenfeltet samtlige 3 kistyper (hovedtyper) representert:

1. Sedimentære vasskislag (Leksdalstypen).
2. Kobberrike gangkiser knyttet til gabbro (Røros—Løkkentypen).

3. Kobberfattige gangkiser knyttet til trondhjemit (Rødhammer—Jorfjelltypen).

Til slutt skal jeg ganske kortfattet få berøre de forskjellige bergarters relative aldersforhold.

Jaspiskonglomeratet, som betegner Løkkenfeltets eneste større diskordans, fører — som tidligere omtalt — boller av grønnstein, felsit, jaspis, rød skifer, marmor m. m. derimot ikke — såvidt jeg vet — av gabbro. Heller ikke trondhjemit er alminnelig som bollematerial i jaspiskonglomeratet. I de fleste blotninger er trondhjemit ikke iakttatt. Men unntakelsesvis, som f. eks. i jaspiskonglomeratet ved Svorksjøen, forekommer den i mindre mengde.

Utenfor Løkkenfeltet er derimot trondhjemit relativt alminnelig som bollematerial i jaspiskonglomeratet, således både på Melhusbladet og Trondhjemsbladet.

Av de 2 dypbergarter, gabbro og trondhjemit, forekommer således iallfall trondhjemiten i jaspiskonglomeratet. Og da trondhjemiten i alminnelighet synes å være yngre enn gabbroen, er det vel også mest sannsynlig at begge disse bergarter er eldre enn jaspiskonglomeratet. Vi må i så fall anta, at den sterke erosjon, som førte til jaspiskonglomeratets dannelse som regel ikke nådde ned til dypbergartene.

Denne oppfatning, som således legger dannelsen av gabbrobergartene og trondhjemitene (og altså også gangkisene) i umiddelbar tilknytning til Bymarkgruppens vulkanisme, er imidlertid ikke sikkert bevist. Det er ikke utelukket, at iallfall en del av våre trondhjemiter også ble dannet i en betydelig senere periode — under den oversiluriske eller kaledonske fjellkjedefoldning.

Når det gjelder fastsettelsen av dypbergartenes alder må vi imidlertid ikke glemme, at gabbrobergarter og trondhjemiter (med typisk eugranitisk normalkornet struktur) hittil ikke er påvist innenfor Hovingruppens områder. Men vi har basiske gangbergarter, dels porfyrisk, dels finkornet utviklet, i Hovingruppen. Og vi har sannsynligvis sure lavaer.

Ved siden av Melhusbladets område, særlig Hølondafeltet, anser jeg Løkkenfeltet som den interessanteste del av Trondhjemsfeltet. Vi finner her — liksom på Melhusbladet — alle formasjonsgrupper. Vi får lettere enn noe annet sted beviset for at det reviderte lagsystem er korrekt. Og vi har samtlige 3 hovedkistyper representert.

ON THE RISE OF SEA AND LAND AND THE FORMING OF STRANDFLATS ON THE WEST COAST OF FENNOSCANDIA

BY

OLE T. GRØNLIE

Introduction.

In 1940 the present author published a paper, "On the Traces of the Ice Ages in Nordland, Troms, and the Southwestern Part of Finnmark in Northern Norway" (4). This paper was meant only to be a preliminary communication as the material used there was partly insufficiently worked out. Many localities had not come into their proper places, some of the shorelines were doubtful, and a coordinate system, which was tentatively introduced, was less practical in use, etc. I therefore found it necessary to reconstruct the diagram, Pl. II, extensively. During the five years of war and occupation only little work could be done, and collection of new material was practically impossible. On that account I have been compelled to work with the material which was at hand, and for the rest utilise in the best possible manner the points of the diagram. It is the result of this work which is presented here.

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1. Measurements of Shore-lines from Northern Norway.

A . after a figure in the following list of the localities means "a good shoreline", and a : means "a strongly engraved and fine shoreline".

1. Sørvær on Sørøy	3.8 5. 11. 12.55 18.3 19.7 28.8 43
2. Store Kamøy on Sørøy	5.9 8.3 10.1 18.3 21.9
3. Bleik on Andøy	3.5 5.8 13.5 15.4 17.5 20.2 23.9 24.5 25 26.6 40.4? 48?
4. Andenes on Andøy	3.4 3.8 5 6.6 8
5. Eggum on Vestvågøy	0.9 1.5 2.4 3 4.2 5 5.5 5.9 7 7.4 8.6 9 9.9 11 13.8 15 16.5 18.6 24.2 26 42
6. Vikan near Sørvær	5.5 9.3 12.7 14 16.6 20.4 24 33.5 37.9 45.6
7. Skarvnæringen on Sørøy	22.6 23.8 34.1 39.2 42.4 44.1 51.3
8. Bø on Andøy	3.3 6.7 13.6 16 18.3 24.5 28 42.9
9. Høynes on Vestvågøy	4 8 18.1
10. Kvalnes on Vestvågøy	4 8.3 18.5
11. Skagen in Bø, Langøy	6.1 11.3 15.3 22.2 26.2 35.8
12. Vik on Vestvågøy	2.2 2.9 3.7 4.1 4.6 5.9 6.4 7.9 10.3 14.1 19 24.1 55 68 108—
13. Nykksund on Langøy	9 14.2 18.3 30 35 60?
14. Trenyken on Røst	4.6 7.9 9.6 16.5 39.9 —
15. Gamvik on Sørøy	11.6 14.9 15.2 16.2 19.5 21.2 29 31 35 40.3
16. Knutstad, Vestvågøy	4.4 8.3 20.1
17. Toften on Langøy	6.1 15 19.7 29.6 39.1 61—
18. Skipsvik on Sørøy	11 11.9 16.7 17.8 24.1 27.4 30.5 33 36,2 38.6 42.6
19. Risøyhamn on Andøy	6.6 15.7 18.9 28,1 32.1—
20. Åse on Andøy	6.7 14.2 19.2 28—
21. Langnes on Hadseløy	6.9 20.8 30.2—
22. Veststrømmen on Sørøy	3.4 6.4 8 10.5 12.2 13.8 19.1 20 21.9 32.4 33.5 36.3 48—
23. Bergvik on Hadseløy	8 18.7 28.9—
24. Vedøy on Røst	5.2 8.2 8.7 9.6 11.4 17.1 33.5 36.3 37.6 48.9—

25. Helgøy	9.6 16 29—
26. Hadseløy, east	8.4 17.3 33.3—
27. Gjerstad on Langøy	7.7 20.5 38.9—
28. Hassvåg, Sørøy, west	3.4 4.8 5 6 9.3 14.4 15.3 16.7 19.8 21 27.9 28.7 38.3 40.4 41.2 51.75—
29. Hassvåg, east	3.4 7.5 7 7.8 11.8 13.8 14.3 18.5 20.5 22.5 24.4 26.9 29.1 32.1 34.1 35.6 37.7 39 40.4 40.5 41.5 52 53.7 top of strandwal
30. Holand on Langøy	5.6 9.4 19.3 40—
31. Strand on Hinnøy	6.2 9.1 21.8 35.1 41.3—
32. Værøy, north	2 2.3 4.6 4.8 5.6 6.2 6.9 7.9 8.4 9.2 10.6 11.1 13.3 15. 17.6. 31—
33. Rødgammen	3.2 9.4 15.3.
34. Skogsfjord, Ringvassøy	4 9.6 17.
35. Varvik	9.5 18.9.
36. Værøy, south	2.8 6. 10.4. 14.4 17.7 32.1 34.3 41.9 61.8 the bottom of a hollow in the mountain wall, 80.5 the marine boundary below a cliff
37. Nødhamnen on Senja	10 18.7
38. Vengsøy, north	3.8 10.2 21.2
39. Breivik on Senja	10.2 17.5
40. Sandvik on Senja	10.3 19
41. Medfjordvær on Senja	10.4 18.1
42. Hassvik, east, Sørøy	3.8 6.3 9.2 13.3 20.2 22 24.6 30—
43. Finnvik on Senja	5.4 12.3 25
44. Kjerringvik on Senja	10.8 21.2
45. Vengsøy, south	10.9 21.9 39.9
46. Kammen on Vannøy	11 12 23 27.4 34.3
47. Gryllefjord on Senja	11.2 23.7.
48. Bukkemyr on Senja	11.4 21.7
49. Finnsæter on Senja	11.5 22
50. Meltefjordnes, Sørøy	1.3 3.6 5.8 9 31.2 41.2 58. 63—64.
51. Vallberg on Vestvågøy	5.5 12 17 23 75.2 a line in moraine.
52. Kårvik on Ringvassøy	2.4 3.9: 12.4 25.1:
53. Finsæter in Kvefjord	4.5 6.0 12.24 25.7 47.3:
54. Tromvik on Kvaløy	12.4: 19.6 23.6 39
55. Rekvik on Kvaløy	4 12.6 23.3 26.7 43.9.

56. Flakstad on Senja	12.5. 26.2
57. Ivervær on Silda	4.9 11.2 12.7 16.4 22.4 26.1 27.5 28.3 29.8 31.6 32 32.7 33.5 36.3 38.5 39 48.1—50.7 53.2—54.2 58 59.7 61.7 63.9—68.9
58. Bremsholmen on Kvaløy	12.5 27.2
59. Andersvik on Karlsøy	7.3 13.4. 30.7 32.6
60. Tronjord on Kvaløy	5.9 13.7 16 17 37.3
61. Urelv on Sørøy	3.7 4.8 6.8 7.7 8.9 11.8 13.9 24.1 25 26.8 (36 39 50.5 65.4?)
62. Hersfjord on Ringvassøy	5.1 13.5 28.8: 33.5 50.6
63. Vasstrand on Kvaløy	5.5 15.3: 26.9 29.8 51.8
64. Mebotn on Sørøy	3.2 7.5 13.6 22 20.4 32.7 60?
65 a. Fuglnes, Hammerfest	3 6.5 10 13.2 19.2 26 30 34.6 40.9 51.4
65 b. » »	3.1 7.6 8.4 11.9 14.4 16 18.1 19.3 27.8 29.9—34.6 44.8 46.9 47.3 47.8 48.2 51.5 52.4 58.2 58.7—
66. Karlsøy near the church	7.5 13.9 32.7
67. Kalfjordbotn, Kvaløy	5.9 13.9 36.3
68. Løkvik on Senja	14.2 29.5 34 62.7?
69. Skattøra on Ringvassøy	3.5 6.5 14.3 24 30 53.2
70. Sigerfjord on Hinnøy	7.5. 14.3 22.8 30.2. 38.7. Moraine terrasse 110
71. Røssnes on Ringvassøy	6.7 14.6 23.8 36.9:
72. Bjarkøy	14.3 33.1: 42.1
73. Simavik on Ringvassøy	6.6 14.1: 32.5. 42 terrasse.
74. Gresnes on Hinnøy	3.3 9.5 14.6 28.5 48 above 100 m terrasse.
75. Buvik on Kvaløy	14.7: 32: in rock.
76. Gamnes on Ringvassøy	6.6 14.8 23.5 36.5.
77. Futrikelv, Kvaløy	7.3 14.9 34.1.
78. Lilleeng on Reinøy	3.1 6.8 15.8 34 in limestone.
79. Kattfjord on Kvaløy	1.4 5.4. 15.5 32.4
80. Gunnesdal on Hinnøy	5.7 8.6 15: 32.5: 42.5 55.4 73.6.
81. Glimma on Ringvassøy	7 15.5 38.5 48 top of a moraine.
82. Lanes on Senja	6.4 15.4 33 in solid rock.
83. Langnesbukt, Hinnøy	3.5 16.4. 33.2 39.
84. Ganslått on Senja	6.6 15.4 34.5 67.9.

85.	Krabbenes on Kvaløy ...	6.7 15.8 38.
86.	Finnkrokan on Reinøy ...	6.4 15.8 24.8 32.6 39.3 in solid rock.
87.	Kraknes on Kvaløy	6.1 15.9 38.4.
88.	Rottenby on Reinøy	6.6 15.9 25.6 34.1 39.7 70.6? 93.4?
89.	Greipstad on Kvaløy ...	3.3 5.8. 16.3: 28.5 35.7 39.3.
90.	Bakkejord on Kvaløy ...	7.1 10.4? 15.8 16.8? 38.3 53.6
91.	Mjelde on Kvaløy	6.8 15.8 38.5 42.
92.	Ersfjordbotn on Kvaløy	5.3 16.2: 35. 53.
93 a.	Storelv on Kvaløy	6.5 16.7 40.1 in solid rock.
93 b.	Finnland on Kvaløy ...	6.9 16.7 40.7 » » »
93 c.	Finnvik on Kvaløy	16.7 39.9
94.	Vang on Senja	8 16.4: 37.7 in solid rock.
95.	Grøssnes on Reinøy	7 17 24.7 32.1 41.
96.	Strømsnes on Senja	7.8 17 40.4. Line in moraine 195—200 asl
97.	Håkøybotn on Kvaløy ...	6.5 18 30.5 43.
98.	Flesnes on Gullesfjord ...	3.5 16.8 33.4 36 414:
99.	Skittenelv	7 17.2 40.7
100.	Lenvik	2.1 5.2 9.5 16.9: 26.3 39.9 47.6.
101.	Bay east of Øxnes	4.1 7.5 17.7 25.7 38.2 63.1 86.7 94.3
102.	Håkøy at Tromsø	17.3 26.5 41.4
103.	Tønsås on the mainland	7.8 17.4 42.1
104.	Movik » » »	6.8 17.5 37.9 42.
105.	Borkenes in Kvefjord ...	2 3.3 17.7 42.1 53.4 75.4 90.5.
106.	Sandnes on Tromsøy ...	7.6 18.3 27.3 36.6 42.3
107.	Tønsvik on the mainland	7.9 17.9 35.2 42.8
108.	Risvoll on the mainland	5 7.5 17.6 38.6 41.7
109.	Breivik on Tromsøy	7 17.8 38.5 42.7 in solid rock.
110.	Stakkevollene on Tromsøy	7.4 18.5 27 38.9 44
111.	Strømsgård on Kvaløy ...	6.1 17.6 30 41.7: 50.6 68.6
112.	Snarby on the mainland	8.1 17.9 29 38 44.2
113.	Kvitberget on Kvaløy ...	6.2 16.5 42.4 55.8
114.	Innpollen on Stjernøy ...	7 12.5 16.8 27.8 40.8 45.1 51 60.4.
115.	Skognes on Senja	10.7 18.5 33.3 42 48.3 in solid rock.
116.	Skjervøy	9.3 19.1 31.5 46.9 50.5 55.4
117.	Sandsøy	3.3 7.5 13.9 18.9 22.5 36.3 49.1—
118.	Jøkelfjord	11.1 22.3 25.3 32 35.4 49.1 55.9 66.3 76.4
119.	Giævereiva on Tromsøy	7.8 18.4 44.

120. Durmålsvik in Lenvik	10 18 30.4 39.6 46 in rock 71.2 in rock.
121. Nord-Lenangen	7.8 18.6 28. 37.8. 46.9 67.8 75.4.
122. Eidstrand on Ulsfjord	10.5 18.7: 28.7: in rock 50.8 78. 89.1 99.4 118.4 136.
123. Krokelv on Tromsøysund	7.5 19.1 27.5 38.1 45.
124. Tomasjord on Tromsøysund	3.1 7.5 19.4 30 39.8 47.6 in rock 72.5 (93 109 121)?
125. Hungeren on Tromsøysund	7.2 19.2 30.5 45.8 69.9.
126 a. Kallsletta, Tromsøysund	7.2 19.2 28.7 37.6 45 72?
126 b. Solli on Tromsøysund	7.2 19.3 29.3 37.5 45 70.3?
127. Våg west of Harstad	11.4 18.5. 26.2 40.4 45.2 56.5 84.5 86.5?
128. Myrlund on Senja	9.6 18.8 31.7 48.6 in solid rock.
129. Sverresborg, Tr.sund	7.8 19.4 26.5 39.6 46.5 57.4 67.9 72
130. Tromsdalen on Tr.sund	20 27.2 47.4.
131. Steinbakken on Kågøy	6.5 7.6 9.7 12.9 19.6 46.6:
132. Fritsvoll in Lenvik	9.9 19.5 31.3 39.7 44.9 50.9 71. 77:
133. Brokskaret on Malangen	10.2 20.2 33.4 38.2 46.8
134. Tenskjær » »	8.2 19.5 33.9 41.4 50.
135. Andsnes » »	6.4 10 19.8 45.5 50.1.
136. Bentsjord on Rystrømmen	4.1 10.9 20.2 38.8 47.5.
137. Vassvik on Senja	11.4 20.1 51.8
138. Valanhamn in Kvenangen	2.1 12.4 20 31.5 41.6 48.9 56.9.
139. Refsnes on Senja	17.8 51.
140. Gammelsæter on Senja	5.6 8.3 15.3 17.5 41.8
141. Oldervik in Ulsfjord	7.3 11 20.5 37.5 44.5 46.8? 52.
142. Selnes. » »	10.5 20.8 30.1 42.6 51.9 100 (a).
143. Alteidet in Kvenangen	2.5 10.9: 13.3 20.2 24: 34.9 45.9 52.9 57.9 77.6
144 a. Bukkskin in Lenvik	7.4 11.9 20.8 50.6.
144 b. Stonglandseidet, Senja	20.7 48.9.
145. Kanebogen on Vågsfjord	8.3 12.7 20.8 in rock 35.7 38.3 49 58.5.
146. Kraknes on Malangen	10.8 21 35.1 45.5 56.4.
147 a. Laukslett on Ramfjord	8 21.2 53.
147 b. Sletta » »	21.1 53—79.
148. Klauvnes on Uløy	6.8 10 21 31.3 48.3 55.2

149. Sør-Lenangen	10.2 21. 37.7 43 53.8.
150. Nordbotn, Ramfjord	8.4 21.1 23 32.1 42.6 51.5. 52. 61.5.
151. Skattvik on Senja	19.5 54.5 in solid rock 59.? 62.
152. Bjorelvnes in Lenvik ...	10.3 17.3 21.2. 40.1 56.1.
153. Bundjord » » ...	11.5 21.5 36.7. 47.2: 56.6: in solid rock.
154. Gunnarheim on Solbergfjord	12.9 34.4 83.3?
155. Holmslett on Tr.sund ...	7.5 21.5 31.3 41.2 49.5
156. Bakkeby on Malangen ...	11.1 21.5 57.7
157. Skorpa in Kvenangen	3—4 6.7 13 18 22 26 30 38 39 58 (a).
158. Bakkelund on Øksfjord N. R.	2.1 7.1. 12.9. 21.9 33.9 60: in rock.
159. Bærskogen, Ramfjord	35.7 38.1 43.8 50.3
160. Sanda on Træna	3? 8 11.8 18.8 21.8 22.3 35.3 36.5 43 50 54.5 56.5 75 89.
161. Kristofferjord, Ramfjord	8.5 22.1 33 43.9 53.1 57?
162. Bakkeby in Nord-Reisa	4.9 8.5 20.3 22? 31.4 39.9 55 61.4 64.9
163. Nålelv on Burfjord	6.0 15.7 22.7: 33.6 61.9 65.8 in rock 79.5.
164. Bjørkelv on Ramfjord ...	8.2 22.9 33.4 44.7 58. Side moraines 250 and 292
165. Breivik on Ulsfjord	10.6 21.6 40.3 51 62.4 78.5. Line in moraine 284.
166. Storvik in Malangen	6.4 12: 22.5 37.5 50.4 60.3.
167. Ulsnesvik, Ulsfjord	10.3 22.4 in solid rock 37.3 49.5: 58.9.
168. Storslett on Uløy	9.5 21.8 40.1 51.3 62.5.
169. Sætra on Uløy	9.3 23.1 41.4 51 62.9.
170. Kilbotn on Hinnøy	8.7 12.7 22.8 35.9. 47.1 59.1.
171. Sakrijord, Ramfjord	8.3 23.2 35.5. 45.8 59.
172. Storvik in Nord-Reisa ...	3.6 9.5 20.9 22.4 34.7 38.6 57.1 62.3 73.9 77.9
173. Vikstrand on Senja	11.5 22.9 58.3. Side moraine 260.
174. Haugrud on Malangen ...	11.4 12.80 23.1 39.1 51.7 62.1 76.
175. Sandnes in Kvenangen ...	2 3.4 6.1 13.2 20.2 23.4 38.7 57.6 66.6
176. Langhamn on Dyrøy ...	9.5 23.6 60.6.
177. Mortenhals in Malangen	6.5 12.4 23.2 52.1 65.

178. Ulvik-Kongsvik, Tjelsund	7.5—8 12 32 38 41.2 53 58—59 (a)
179. Andersdal, Balsfjord ...	12.8 24.4 51.6 58.9
180. Sørvik on Hinnøy	8.8 13.5 24.9. 39.5 45.4 51.8 62.9.
181. Rotsundelv on Rotsund	3.8 6.4 10 23.8: 41.2 51.9: 62.3.
182. Langnes, ytre, Ulsfjord	11.5 23.6 in rock 38.1 62.7.
183. Havnes in Lyngen	10.2 23.8 42.3 53.1 63.3.
184. Skogen near Finnsnes ...	13.7 23.3 42.8 54.9 67.
185. Skutvik in Malangen	4.4 12.4 24.2 in rock 45.6 52.4 72.1.
186. Skarmok in Ulsfjord	7 13.5 22.8. 28.3: 35: 43.8. 58.2 69.1.
187. Nyheimen in Malangen...	12.8 24.4 38.4 53.4 64.4.
188. Målsnes » » ...	12.5 24.5 32.8 55 65.
189. Eidet » » ...	12.4 24.8 53 85.
190. Horvik on Tjelsund	8.2 12.4 25: 38.6 60.5. Line in moraine 80.5.
191. Evenskjær, Tjelsund ...	10 25.
192. Strømsnes on Sørfjord ...	6.3 11.9 25. 35.5 44.5: 58.7: 65.2 72.
193 a. Labukt in Balsfjord ...	13 25.3 60.3
193 b. Steinsland, Tjelsund ...	8.3 13.9 24.8 43.2 56.8 71.3
194. Hammervik in Lyngen ...	10.4 25.1 43.5. 53.7 62.8: 64.4
195. Skogli in Balsfjord	13.9 25.3 40.3 51.2 61.3.
196. Furstrand on Solbergfj.	14.2 25.1 64.1.
197 a. Gausvik on Tjelsund ...	8.8 13.6 25.3: 41.3 55.3 64.5.
197 b. Bjørg, Sør-Reisa	14.1 29.9 34 77.9 82.
198. Lundeberg, Gisund	14.1 25.4. 48.2 57.5 69—70.
199. Skogan, »	7.7 13.6 25.4 44.1. 57.5 72.
200. Kastneshamn	10.5 26.3 68.4.
201. Sandtorg on Tjelsund ...	8.7 13.8 25.2 in rock 42.9 56.9 65.7 in rock.
202. Engenes in Lyngen	10.7 25.8 33.7 45.1 55.8 66.
203. Tømmerbukt, Kvenangen	2.8 5.2 7.5 10.1 11.9 14.8 18.1 24.9. 26.2 36.7. 43.5 47.5 50.4 53.8 55.9. 59.6 62.5 64.6.
204. Bø on Engeløy	3 6.1 10.5 16.8 24.1 27.9 35.6 43.5 65.8.
205 a. Malangseidet, Balsfjord	7.6 14.7 26.2. 40.8. 56.4 61.8.
205 b. Sæter in Malangen ...	13.3 26.1 41.6 67.1.
206. Bakkland, Tjelsund	8 14.6 26.2 45.7 59 74.2
207. Sandstrand, Vågsfjord ...	8.4 14.5 26.1 43.8 55.5 65.4 67.9 69.9.

208. Badderen in Kvenangen	2.7 4.2 7.9 13.8: 19.8: 26.3: 31.1 32 36.3 44.7 50.1 60.9 68.8 75 88?
209. Tovik on Astafjorden	14.7 26.5 43.6 56.6 69.2 72.
210. Sommerbukt, Sørfjorden	12.6 14.3 26.4: 48,2. 59.8 75.8.
211. Grunnreis in Sør-Reisa	14.8 26.7 43.2 50.4 63.2 76.5.
212. Hestnes in Balsfjord	4.3 8.5 14.6 27 52.9 56.8 68.9.
213. Smørgard in Sør-Reisa	7.8 15.1. 26.8 51.8 64.9 67.4 81.
214. Renså on Astafjord	14.7 27.2 43.6 56.6 72.1.
215 a. Naustvik in Balsfjord	15.7 26.5 53.6 68.4 87 114
215 b. Frøsenelv near Skånland	7.2 8.4 14.4 27 47.7 59.2.
216. Stornesbukt on Sørfjord	15 27 50.4 64.7 79.5.
217. Gottesjord in Sør-Reisa	15.5 19.2 26.9 53.2 67.9 84.9.
218 a. Svartnes in Balsfjord	15 27.1 42. 53. 66.5
218 b Hamnvik	3.9 11 19.5 30.9 54.4 58.6 66.8
219. Elvebakken on Astadfjord	14.5 27.6 44 56.7 74.
220. Tyttebærvik in Kjosen	6.6 13.7 27.5 48.1 61.8 75.5.
221. Skagstad on Engeløy	3.1 5.6 11.3 16.8 20.1 23 25.1 28 35.3 37.3 41.3 43.1 48.2 50.4 53.4 58.4 68.4 92:
222. Rødberg, Tjellsund	8.5 14.4 27.5 45.7 59.7 74.7.
223. Skognes on Sørfjord	8 17.6 27.8. 42.7 52.6 65 80.1.
224. Nygård on Astafjord	14.9 27.5 44.9 58.4 59.8? 75.3.
225. Skar on Ofoten	8.6 27.6 75.5 in solid rock.
226. Olderelv, Lyngen	6 12.8 27.8 48 59.6 75.7. Lines in moraine 300 and 400
227. Lyngseidet, Lyngen	13.6 28.4 49.8 63.2 76.2.
228. Laksvassbukt, Balsfjord	17.1 28.4 68.
229. Storelv on Sørfjord	8 15.2 17.8 24.8 27.3: 34.5 42.2 53.4 59.8 68.9 74.8 83.5.
230. Lauvdal	9.3 26.4 29.7 54.7 60.3
231. Sørfjordbotn, Malangen	4.1 6.2 9.8 14.4 28.9 63.5. 75.8
232. Tårstad on Ofoten	13.5 29 49 62 76 (a)
233. Lavangsnes	29.2 76.8.
234. Lakseidet in Malangen	12.8 15.9 26.2 70 89.4.
235. Naustnes in Balsfjord	15.6 29.5 72.9.
236. Middagsbukt, Balsfjord	9.5 16.2 30 48.4 78.
237. Sørstrømmen, Sørfjord	9.7 20.1 29.9 56.2 76.5 89.5?

238. Porsøen, Ofoten	13.3 30.1 in rock 48.2 64.1 67.4 79.4
239. Leirvik, Sagfjord	3 14 21.6 30.5 40 55 71.8.
240. Modalen, Sagfjord	3.5 14.7 23.7 34.8 80?
241. Vika on Vega	2.5 6.8 7.5 18 27.1 37.8 63.1 65.9 81.4 98.5 in solid rock.
242. Balteskar, Grovfjord ...	16.6 30.9 46.8 60. 77.6.
243. Elvebakken, Balsfjord ...	4.2 8.6 12.3 15.1 18.1 31 37.6 46 49.9 62.4 80.5.
244. Ørnes, Lyngen	13.8 29.2 in solid rock 50: 65.9 78.1:
245. Djupvikpollen, Sagfjord	3.5 7 17.3 24 31.2. 44.7 55.8 68 82.4:
246. Brennsundvik, Folla	2.8 6 13.5 20.2 37.9 49.3. 60.7 67.9 78.9 91.7.
247. Grov, Grovfjord	6.3 9.6 31.6 46.4 63.1 74.7 80.7.
248. Årsandvik, Grovfjord ...	9.8 31.5 47.7 68.5 81.2.
249. Kroken, Lyngen	13 31.2 52.2. 64.3. 81.
250. Lien, Ofoten	10.5 14.6 31.9: 51.7 67 81.8
251. Tennes, Balsfjord	13.4 17.6 31.7 78.
252. Dalen, Lyngen	14.6. 31.6: 44.5 53.8. 69.3. 82.6.
253. Bogneset, Tyssfjord	3.4 6.6 13.2 19.7 31.9: 46.5 — — —
254. Gullvik, Sagfjord	3.5 12.8 23.4 32.3. 40 47.4 64.7 83.
255. Lilandskaret, Ofoten ...	8.6 14.6 22 32.5. 51.9 69 81.7
256. Skrovkjosen, Tyssfjord	3.2 6.8 13.7 19.4 26.9 31.9 43.4 45.5 69.7 73.5 83.8 100?
257. Kjær, Tyssfjord	3.4 6.5 21.6 24.4 37.1 40.9 53.6 64.8 83.9
258. Liland, Ofoten	14.2 17.2 33.3 82.
259. Saltvatn, Grovfjord	26.4 32.6 47.5 68 84.5
260. Ballkjosen, Folla	2.5 5.4 10.8 16.5 22.5 34.6 38.3 51.5 66.3 69.3 70.9 83.5 99.6.
261. Mælen, Balsfjord	3.6 7.6 11.1 15.2 18.8 25.2 32.8 52.4 73.1 81.2
262. Repvik, Efjord	3.4 6.2 12.3 17 23.6 28 33.8 39.3 53.7 62.4 67.3 78.
263. Leinesleira, Folla	2.9 5.8 13.9 21.4 28.3 35.4 37.6 49.3 58.8 68.9 76.7 82 94.
264. Djupvik, Ofoten	9.3 14.7 33. 51.8 61.7 68.2 85.
265. Laberg, Gratangen	14.2 25.8 34.5 38.5 49.2 62.6 82.6.
266. Årstein, Gratangen	10.7 18.7 23.1 35.4 37.9 49.3 58.3 85.5 93.7.

267. Storsteinnes, Balsfjord... 6.8 12.9 16.8 22.3 33.6 36.2 49 72.2 83.6
268. Lenvik i Ofoten .... 8.5 14.8 33.8 55.3: 70.5 86.3.
269. Sjenken, Folla .... 6.2 14.5 19.5 20.7 35.3 38 48.9 59.9 70.3 83.4 94.2.
270. Soløy, Lavangen .... 8.9 17.9 30.7 35.1 48.3 52.6 79 83.6.
271. Marknes, Balsfjord 17.6 33.8 83.6
272. Bjørn, Dønna 6.7 10.7 17 23.5 29.2 37.1. 51.8. 59.8 73 79.4 92.3:
273. Skibotn, Lyngen .... 14.8 32.6 47.3 54.8 57.6 65.6 85.3.
274. Spansdal, Lavangen ...... 11 17.6 26.3 34.8 75.1 86.2.
275. Hornesbukt, Lyngen ...... 7.4 15.7 32.9 54.9 70.8 84.
276. Gratangsbotn, Gratangen 6.7 8.3 14.9 18.7 26.4 46.8 49.6 63.2 71.6 74.9 79.6 93.3
277. Kjerringøy .... 6 13.5 21.2 38.6 51.9 60.7 69.3 79 96.2.
278. Heldal, Folla .... 3.2 8.2 12.6 17 22.5 26.5 28.5 38.6 52.5 62.8: 71.7 85.9 89.8 100.7.
279. Mjelde south of Folla ... 5.6 14.2 20.2 38.9 51.8 59.5 68.2 80.7 95.3.
280. Elvesletta, Ofoten .... 7.6 15 36.5 53.1 71 87.4.
281. Hopen, Folla .... 2.9 3.9 7.5 8.3 16.2 22.7 35.3 39.5 54.5 63.5 72.1 83 83.2 102.2.
282. Eidet, Folla .... 5 6.7 9.5 15.7 21.4 27.1 30.2 50.1 62.1 74. 82.6 96.7.
283. Lia, Sagfjord .... 3.4 10 14.6 24 34.5 53.2 66.8 73 80.2 85.
284. Nord Fugløy 3.1 6.3 12.1 23.7 39.3 56.9 69.1 81.6 88.6
285. Kirknes, Lyngen .... 10.7 22.4 28.7 32.1 34 52.4 56.3 66.2 70.2 85.
286. Stefjord, Tyssfjord ...... 3 5.1 7.5 12.6 15.8 25.4 33.7 46.7 54.7 65 66.7 79.2 100.2.
287. Movik, Folla .... 3 7.7 15 21 24.4 34.4 48.5 50.2 59.3 67.6 79.3 82.7 97.2.
288. Kobbenes, Efjord .... 3.8 7.4 12.7 18.4 19.7 25.2 28.9 37.5 43.4 57.2 68.2 75.1 82.5.
289. Hestun, Hamnøy .... 3.3 9.5 15 18.6 23.2 38.3 56.4 64.7 86 108.1.
290. Fossland on Tomma 3 10.6 15.1 19.8 26.8 31.1. 38.9 43.1 51.6 60.8 79.3 84.8 91.9

291. Øijord, Folla	7.0 13.2 20.1 25.7 39.5 47 53.2 58.4 68.5 82.7 85.2 99.1.
292. Stavnes on Åmøy	3 8.8 18.2 29. 38.1 48.1 56.8 70.3 84.3 +1?
293. Vevelstad	3 10 14.1 19.4 23 25.3 30.4 40.8 70.1 89.1 109.9.
294. Bjørsvik, Folla	8 13.8 21.4 28.3 40.5 54.5 72.8 85.5 104
295. Fagervik, south of Rana	7.5 14.3 21.8 28 43.3 50.7 71.2 95.1 95.5
296. Brattland, Aldersund ...	3.4 10.9 16.5 20.1 33.9 37.7 45.6 56.2 62.5 69.5 89.4.
297. Reinvik, Folla	2.8 5.8 11.2 17.3 27.8 36.5 44 46 49.8 52.6 62.4 78.5 85.5 91.3 102.6.
298. Storvik in Gildeskål	3.1 12.5 22.9 26 37.4 62.1 74.6 92.6.
299. Botnfjord, Folla	7.7 12.9 15.4 22 42.5 55.8 69.9 87.5.
300. Alsvik on Sandhornøy ...	3 6.6 21.5 30.5 39.5 47.1 53.1 56.3 67.2 75.1 92.2 94.
301. Stavjord, Folla	4.6 9.3 15.7 20.1 28.4 35.2 37.2 45.2 69.1 71.9 84 87.2 104.4.
302. Åkvik on Alsta	3.1 14.2 20.2 27.5 36.5 42.2 62.5 70
303. Kvarsvik in Gildeskål ...	3 11.3 12.7 23.1 40 47.1 68.3 75.6 92.1 93.1
304. Riksen on Hannesøy	2.5 11.3 21.2 28 37.3 49.1 60.7 76.6 81.8 97.9:
305. Sjunkvik, Folla	5.1 12.8 18.6. 34.6 43.3 54.4 67 86.4 98.9 101.9.
306. Eidet, Velfjord	6.7 14.5 18? 19.6 39.9 57.5 61.2 72.2 87.9 101.2 108.7 121.6:
307. Musken, Tyssfjord	3.3 8: 14.8: 28.6: 36.2 42.9 52.2 65.9 78.7 102.3.
308. Mosvoll in Meløy	2.6 5.9 8.8. 16.8 26.9 34 37.8 41.6 48.7 51 62.2 69.3 89.5.
309. Visthus, Visten	6. 11.8 22 35.4 38.4 38.5 42.5 53.2 64.5 77.5 88.5 106.9 122.9
310. Straumen, ytre Tyssfjord	2.8 7.1 12.7 15.2 22.1 25.9 31.7 37.6 40.6 45.8 56.1 58.5 75.2 98.1.
311. Sørfjord, Melfjord	3.1 7.1 9.3 20.6 24.2 28.4 37.7: 59.7 68.9 87.1 100 above a broad terrasse.

312. Lysfjord in Vik	5.1 14.6 17.4 23.4 24.6 27.5 45.3 49.9 53 56.7 62.7 84.9 92.5 98.4 103.9. Moraine 115
313. Korsvik, Folla	7.1 10.2 14.2 22.9 34.7 40.4 48.6 49.6 54.9 61.3 62.8 76.8 93.7 97.4.
314. Sandåg, Glomfjord	3.4 8.8 14.8 29.9 47.7 66.6 72.5 82.7 92.6
315. Kjeldal, Bjerangsfjord	7.4 15.3 19.9 30.7 40.5 51.2 69,3 80.5 91.7 99 108.6. Fine terrasse 118 a. s. l.
316. Båtberget, Ankenes	12.6 20.3 41 92.8.
317. Sørfjordbotn, Gildeskål	3.2 6 15 18 20 38 94.5.
318. Sjunkfjordbotn, Folla	8.3 10.2 14 21.6 30 40 54.1 70.2 78.2 108
319. Mørsvikbotn, Folla	2.6. 5.2 7.3 10.3 17.7 25.4. 34.9 43.8 53.4 62.2 72.5 87.2 99.2 100 105 106?
320. Kjelling on Beiarfjord	3.7 7 9.2 12.7 19.7 37.4 41.4 53.1 56.7 63.5 83.1 ————
321. Sandnes in Nesna	3.4 7.4 15.3 33.6 41. 77 84.7 88.5 95.4 98.5 109.1.
322. Malm in Vik	3.5 6.8 20.1 22.1 28.4 41.1. 65.5 114.6: 131.6
323. Risnes, Rødøy	3.6 10.2 15.2 30.2 48.4 — — — —
324. Gjervikvalen, Melfjord	3.1 6.2 8.2. 12.6. 21 25.3 41.6 49.5 60.2 75.8 81.9 99.4 over terrasse.
325. Sørnes, Vefsen	6.9 14.4 21.8. 28.1 34.3 37.9 43.7 54.9 64.8 75 82 92 103
326. Botnet in Bindalen	5.9 18.1 35.2 41.9 46 62.4 73.5. 84.6 103
327. Breivik, Tjongsfjord	3.7 4.8 20 29 32.6 41.6 49.2 58 72.8 73.3? 92.6 100.5.
328. Bjørnå, Visten	9.4 22.4 38.1 44.4 47: 49.9 67.6: 84 95.1.
329. Hestvik, Folla	8.9 14.4 25.7 42.2. 55.3 68.3 80.1 86.4 97.5.
330. Laingen, ytre Vefsen	3.5 7 13.6 21.6 40.7 42.7 53.3 60.1 61 68.2 75.6. clay to 60 a. s. l.
331. Vassås in Bindalen	5.9 12.6? 18.4 42. 45 55.3 57.3?

332. Leiren, Leirfjord	3.4 7.7 13.2 17 20.9 31.6. 39.1. 49.4. 54.3 60.3 70.1? 73.3 80.6 88.5.
333. Tuv in Salta	4 8.6 14.9 22.4 36 42.2 49.8 61.7 82.5 — —
334. Holand, Holandsfjord ...	3.7 10.2 20.3 31.5 42.5 43.2 54.7 60.1? 78.4 80.4 92.3 100.4.
335. Grunfjordbotn, Tyssfjord	4.1 10.6 14.3 24.5 33.9 41 54 64 81 99.1.
336. Røssvik in Salta	7.8 14.6 23.1 42.5 55.6 63 70.8 98.6.
337. Våtvik, Melfjord	4 10.1 17.6 22.6 32.9 43.1 49.7 55.9. 70 85.2.
338. Kallvik, Folla	8.4 15.4. 25.9 43.4 51.7 61.5 82.4 100.3 118.
339. Glomfjord	11.8 18.3? 27.3 42.6 68.6: 101.5 o. f. t.
340. Botteløra, Holandsfjord	3.5 8.8 15.8 22.1 43.7 64.5. 104.9
341. Eggesvik in Beiarn A ...	5 9 15.5 20.8 27 30.5 38 44 50.5 51.8 53.1 55.4 62.5 68.8 78 81.3 87.3.
342. Kvarv, Folla	3.3 8.3 13.4: 25.6 43.5 57.3 72. 87.4. 104.3
343. Engan, Folla	8.9 16.8. 27.6 42.4 59.7 61.8 77.5 86.2 104.6 106.2 110.2.
344. Kobbelvmoen, Folla	13 26.6 34.6 43.4 57.8 60.9 74.4 87 122.3
345. Hommelstø, Velfjord ...	6.6 16.8 31.4 45.4 57.4 64.6 70.6 90.5 108.5. 119.3.
346. Hellemobotn, Tyssfjord	3.9 8.7 14.5. 23.6. 29.4 40.9 45 63.1 — — —
347. Sørfjordmoen, Folla	5.3 16.4 25.3 40.3 60.9 85.5 109.1.
348. Stiauren, Sjona	3.2 5.8 12.8 16.7 25.9 39.3 78.9 90.4 96.7 105.
349. Søfting, Vefsen	2.3 5.3 8 17 22.6 29.1 45.6 56.8. 67.8 81.2 92.4 103.8 114.2 above fine terrasse.
350. Nordland in Beiarn	4.5 8.8 11.8 14.8 21.8 41.5 80.3 84.5 96 104.5.
351. Børjeør, Velfjord	7.6 15.5 28.3 39.9 47.8: 57.4 64.8 76.6 95.4 114.1 123.5 115.3.

352. Torkilseng, Folla	9.4 29 45.9 54.2 57.1 74.1 97.5.
353. Dokkmo in Beiarn	5.5 15.9 21.4 26.9 32.3 35.2 — — —
354. Melfjordbotn A	2.9 6.2 11.7 15.8 22.6 33 35.7? 42.7 45.7 52.1 61.5 72.7 79.1 84 100.4
355. Moldjord in Beiarn A	4.1 5.5 6.8 15.7 20.6 43.9 47.4 88.2
G	6.5 16.4 42.1 45.3 49.3 89.2.
356. Sjonbotn, Sjona	3.6 8.9 13.7 17.9 24. 31.6 34.5? 45 59.2. 68.5? 108.6 over fine terrasse.
357. Halsøy in Vefsen	9 20.5 44.3 47.3 56.7 68.9 80.8. 94.3 102.8 117.7.
358. Breivik in Salta	4.4 9.6 26.6 33.4: 38.9: 46.7: 52.2 64.1 68.3 76.2 86.8 105.4 112.5 120.6.
359. Sukhoi Noss, N. Z.	2.6 19.5 64.6. 75.7. 82.4 84.5 87.9 107.9 115.7 141.1 156.1 175.6 179.6 ... 203.
360. Selfors in Beiarn A	7.9 9.9 12.4 16.7 20.2 21.2 23.3 31.3 32.3 35.5 86 104.1 G: 12.5 18.3 33.1 36.4 44 61.5 82.2 104.5.
361. Utnes in Utskarpa	11.6 27.4 38.4? 42.4 47.9 68. 75.4. 94 107.1 117.4?
362. Strand in Beiarn A	11.9 14.4 28.6 53.4 86.1.
363. Storjord in Beiarn A	12.9 16.7 24.8 32.7 36.8 41 48 49.3 54.7 65.1 79.9 80.4 101.4. G: 16 29.1 35.9 44.8 59.7 66.1 71.5 78.4 99 101.3.
364. Elsfjorden, Rana	7.5 17.5 25.6 29.4 42.1 44 54.9 64.6 80 87.6 102.4 121.8 131.
365. Lillegården, Folla	2.4 10 15.2 26.6 44.7. 59 62.1 74.8 95.7 105.7.
366. Missvær in Salta	4 9.7 16.1 25.4 44 62,3 96.3 104.4 108.3 115.7 — — — 117.7.
367. Ravnå in Rana	49.2 60.4 75.4 80.7 89.6 99.4 104.7 105.6 above fine terrasse.
368. Fosen kapell, Bindalen	6.5 20.9 34.3 56.1 68.2 75.5 95.4 105.
369. Osbakk in Beiarn	22.1 31.9 36.6 49.3 54.8 102.7 104.7 110.7
370. Sætre in Sør-Rana	18 51 74 93 110 120 125 (a).
371. Høgmoen in Beiarn A	46.1 56 58.9 61.9 67.6 96.5 110.1 116.
372. Setså in Salta	1.6 4.5 9.5 17.4 27.6 34.5 47.6 59 79.6 91.1 107.5 120.4 126.1.

373. Bjerka in Sør-Rana	9.4 23.1 22.2 46.6 53.4 64.6 71.7 80.4 83.9 — —
374. Weber Ridge N. Z.	2.9 13 31 42.2 52.2 61.3 68.8 76.5 81.5 99.5 111.9 117.9 132.3 150.6 156.2 171.3 212.2 — — — 218.’ Washed by the sea.
375. Tollå in Beiarn A	40.3 43.9 47.9 66.3 106.8 111.7 113.7 117.5 118.7. G: 40 44.3 68.2 82.3 89.8 104 113 118.7.
376. Serebryanka, N. Z.	3.9 10.5 18.2 30.9 42.2 52.2 68.5 79 102.5 118.2 137.6 156.3 175.5 198.7.
377. Rognan in Saltdalen	5.7 8.7 11.7 17.4 26.8 36.1 — — —
378. Svartishei in Nord-Rana	52.9 61.9 75.1 84.1 94 97.5 105.1 116 129.4.
379. Nestby in Saltdalen	4.4 6.6 11.5 27.6 — — — — — —
380. Bjørnå, Nord-Rana	52.1 65.6 70.4 77.8 82 91.2 98.4. —
381. Ytteren, Nord-Rana	7 16.8 24.6 34.5 39.9 43.4 64.5 82.2 113 115.4 Skaret.
382. Kjellingneset, Nord-Rana	47.1 51 54 59.2 62.5.
383. Sundby, Saltdalen	3.1 5.2 8.8 16: 28.6 36 40 53.6.
384. Bjørnneset, Nord-Rana	50.5 55.5 62.6 75.2.
385. Lynghei, »	51.2 53.2 62.1 76.8 91 moraine.
386. Vensmoen, Saltdalen	17 40 54 57 65.2 72.5.
387. Nordenskjølds Platå, N.Z.	1.9 19.1 31.3 53.8 70.8 100 111.5 117.5 141.9.
388. Øivindgård, Saltdalen	30.5 35.1 47.6 71.6 94.4 113.6.
389. Russånes in Saltdalen	48.8 55.4 65.5 67.7 71.9 75.6 87.4 94.5 100.5 130.3.
390. Pomorskaia, N. Z.	3 14.1 25.4 32.3 40 56.5 71—72 82.9 121.9 135 137—138 156 159.6 197 215.
391. Gribovii, N. Z.	2.6 14.5 20.9 31.1 42.8 57.8 72.3 81.7 99.4 110 121.9 144.7 153.6 158.5 184.4 212.9.
392. Kristendalsnes, Saltdalen	81.2 95.2 102.4 112.4.
393. Arkhangel Bay, N. Z.	3.2 11.7 23.3 36 48.9 58.8 66 73.1 78.5 90 106.9 127.2 145.3 169.5 186.9 203.2 272 238.9 295 305 315 322.
394. Bergulnes, Saltdalen	90 92.4 96.2 99.4 102.3 103.7 107.3 114 123.4 134.5

The material of shoreline measurements which is brought together above is for the most part the same material on which a former diagram was constructed (3), but owing to an extensive re-arrangement of the localities, I have thought it necessary to repeat it here. The material has been collected on the Norwegian coast between Hammerfest and Bindalen, and is for a greater part measured by myself. Of material collected by other investigators there are 10 levellings by Undås from West-Finnmark, viz. the numbers 2, 6, 7, 15, 18, 22, 57, 61, 65 b, and 114, and from A. Grønlie's material from Beiarn the numbers 341, 350, 353, 360, 362, 363, 371, and 375. Of material from Novaya Zemlya I have taken the numbers 359, 374, 376, 387, 390, 391, and 393.

2. The Shore-line Diagram and the Equations of the Lines.

On the basis of the measurements given above, the diagram, Plate I, has been drawn after the method used by Tanner (6). The vertical scale is 1 : 1000, and the horizontal scale is chosen arbitrarily. The Tapes-line — the b-line — has been used as a principal and is given a gradient of 1 : 14. In such a diagram a material of shoreline measurements can be entered in the following way: If the hight of the Tapes level is known in a locality to be, say 30 m, one seeks the point on the Tapes-line in the diagram lying 30 mm above the zero-line. Through this point a vertical line is raised, and on this line is plotted each shore-line which had been measured in the said locality. When thus all the material at hand has been entered, the diagram seems only to be a confusion of points, but on closer inspection these points uniquely determine a series of lines, each representing an old shore-line level, now sloping because the rise of the land was greater inland than on the coast.

The sloping lines in the diagram are so strongly convergent to the left that every pair of levels, arbitrarily taken out and sufficiently lengthened, has an intersection point. Of the greatest interest is a pair of two consecutive lines. The one of such points farthest to the left is the point of intersection between the lines n and m, marked (n, m) or $\frac{n}{m}$. Also a third line, l, goes through the same point. The corresponding points between the younger pairs of consecutive lines lie to the right of (n, m) as shown in Plate III. It is evident that all these points in turn have once been situated in the sea level.

As the old raised levels are drawn as straight lines in the diagram, they can be represented by equations of the 1. degree of the form $y = Kx + B$ in a rectangular coordinate system. As axis of abscissæ it was natural to use the zero-line that represents the present sea level. The axis of ordinates can be chosen more freely. I have once before tried to use such a coordinate system (4); then I chose a line 500 mm to the left of the right boundary line of the diagram as axis of ordinates. From this line to the point (n, m) the distance was 610 mm, as the diagram was 1110 mm long. The same length has also the present diagram. A continued dealing with these things has, however, shown that this choice of ordinate axis was not practical, and therefore the ordinate axis of the present diagram has been chosen 610 mm farther to the left, now a vertical line through the point (n, m) which then gets the coordinates (0, —99.7). As this point does not seem to have taken part in the movements of the land surface, it is supposed to be a point on the western boundary line of the Fennoscandian depression.

The present diagram is thus bounded to the left by the ordinate axis $x = 0$, and to the right by the vertical line $x = 1110$. These two lines are cut by all the sloping lines in the diagram, and the ordinates of these points of intersection can be read with an exactness between 0.1 and 0.2 mm. If these ordinates for one of the sloping lines taken at random are Y and y' then is, in the general equation, $y = Kx + B$, $K = \frac{Y - y'}{1110}$ and $B = y'$

$$y = Kx + B = \frac{Y - y'}{1110} x + y'$$

Ex. 1, Line n: $Y = 305.4$, $y' = -99.7$. $K = (305.4 + 99.7) : 1110 =$
$= 0.3650$

$$y = 0.3650x - 99.7$$

Ex. 2, Line g: $Y = 191.4$, $y' = -84$. $K = (191.4 + 84) : 1110 =$
$= 0.2481$

$$y = 0.2481x - 84$$

Ex. 3, Line b: $Y = 58.8$, $y' = -20.7$. $K = (58.8 + 20.7) : 1110 =$
$= 0.0714$

$$y = 0.0714x - 20.7$$

All the equations inserted in the following pages have been found in the same way as the three equations above.

Nr.	Line	Y	y′	Equation	Cutting with sea level	Cutting with next following line
1.	p	378.5	—92.0	$y = 0.4239\ x - 92.0$	217	(0, —92.0)
2.	o_2	358.0	—92.0	$y = 0.4054\ x - 92.0$	228	(0, —92.0)
3.	o_1	340.0	—92.0	$y = 0.3892\ x - 92.0$	235	(0, —92.0)
4.	o	332.5	—94.5	$y = 0.3847\ x - 94.5$	245	(?)
5.	n_3	328.0	—97.0	$y = 0.3829\ x - 97.0$	251	—
6.	n_2	321.0	—96.5	$y = 0.3761\ x - 96.5$	254	—
7.	n_1	315.0	—97.0	$y = 0.3712\ x - 97.0$	259	—
8.	n	305.4	—99.7	$y = 0.3650\ x - 99.7$	273	(0, —99.7)
9.	m	300.0	—99.7	$y = 0.3601\ x - 99.7$	277	(0, —99.7)
10.	l_2	294.5	—99.7	$y = 0.3551\ x - 99.7$	281	(39, —86.0)
11.	l_1	289.0	—99.5	$y = 0.3500\ x - 99.5$	284	(203, —28 0)
12.	l	282.7	—98.1	$y = 0.3431\ x - 98.1$	286	(136, —51.0)
13.	k_2	277.0	—97.3	$y = 0.3372\ x - 97.3$	288	(146, —48.0)
14.	k_1	273.0	—96.7	$y = 0.3331\ x - 96.7$	290	(162, —43.0)
15.	k	269.5	—96.1	$y = 0.3294\ x - 96.1$	292	(131, —54.0)
16.	i_4	265.0	—95.5	$y = 0.3248\ x - 95.5$	294	(146, —47.0)
17.	i_3	259.8	—94.7	$y = 0.3194\ x - 94.7$	296	(217, —25.0)
18.	i_2	254.5	—93.4	$y = 0.3134\ x - 93.4$	298	(200, —31.0)
19.	i_1	249.0	—92.2	$y = 0.3074\ x - 92.2$	300	(58, —74.0)
20.	i	243.6	—91.9	$y = 0.3023\ x - 91.9$	304	(40, —80.0)
21.	h_4	241.0	—91.8	$y = 0.2998\ x - 91.8$	306	(222, —25.0)
22.	h_3	236.2	—90.6	$y = 0.2944\ x - 90.6$	308	(220, —26.0)
23.	h_{31}	232.5	—89.7	$y = 0.2903\ x - 89.7$	309	(156, —44,0)
24.	h_{32}	229.5	—89.2	$y = 0.2871\ x - 89.2$	311	(139, —49.0)
25.	h_{33}	226.0	—88.7	$y = 0.2835\ x - 88.7$	313	(53, —74.0)
26.	h_2	224.0	—88.6	$y = 0.2816\ x - 88.6$	314	(36, —79.0)
27.	h_{21}	221.0	—88.5	$y = 0.2788\ x - 88.5$	320	(48, —77.0)
28.	h_1	218.5	—88.4	$y = 0.2765\ x - 88.4$	320	(24, —82.0)
29.	h_{11}	214.0	—88.3	$y = 0.2723\ x - 88.3$	324	(487, +44.0)
30.	h	211.6	—86.5	$y = 0.2686\ x - 86.5$	322	(140, —49.0)
31.	g_4	206.8	—85.8	$y = 0.2636\ x - 85.8$	325	(79, —65.0)
32.	g_3	202.9	—85.5	$y = 0.2598\ x - 85.5$	329	(40, —75.0)
33.	g_2	200.2	—85.4	$y = 0.2573\ x - 85.4$	332	(45, —73.0)
34.	g_1	197.9	—85.3	$y = 0.2551\ x - 85.3$	334	(125, —53.0)
35.	g_0	195.5	—85.0	$y = 0.2527\ x - 85.0$	336	(217, —30.0)
36.	g	191.4	—84.0	$y = 0.2481\ x - 84.0$	339	(97, —60.0)
37.	f_2	188.2	—83.7	$y = 0.2450\ x - 83.7$	342	(50, —72,0)
38.	f_1	184.0	—83.5	$y = 0.2410\ x - 83.5$	346	(263, —20.0)
39.	f_0	177.6	—81.5	$y = 0.2334\ x - 81.5$	349	(255, —22.0)
40.	f	173.6	—80.3	$y = 0.2287\ x - 80.3$	351	(277, —19.0)
41.	e	168.1	—78.5	$y = 0.2222\ x - 78.5$	353	(321, — 7.0)
42.	d_5	163.7	—76.7	$y = 0.2166\ x - 76.7$	354	(103, —54.0)
43.	d_{51}	160.8	—76.4	$y = 0.2137\ x - 76.4$	358	(328, — 6.0)
44.	d_4	156.0	—74.4	$y = 0.2076\ x - 74.4$	358	(182, —37.0)
45.	d_{41}	154.0	—74.0	$y = 0.2054\ x - 74.0$	360	(129, —48.0)
46.	d_{42}	150.9	—73.6	$y = 0.2023\ x - 73.6$	364	(56, —62.0)
47.	d_{43}	149.1	—73.5	$y = 0.2005\ x - 73.5$	367	(333, — 7.0)
48.	d_3	146.0	—72.2	$y = 0.1966\ x - 72.2$	368	(286, —16 0)
49.	d_{31}	143.7	—71.4	$y = 0.1938\ x - 71.4$	368	(488, +23.0)
50.	d_{32}	141.0	—69.3	$y = 0.1895\ x - 69.3$	366	(238, —24.0)
51.	d_2	139.2	—68.8	$y = 0.1874\ x - 68.8$	367	(71, —56.0)
52.	d_{21}	137.8	—68.7	$y = 0.1860\ x - 68.7$	369	(222, —27.0)
53.	d_{22}	135.4	—68.1	$y = 0.1833\ x - 68.1$	372	(382, — 2.5)

Nr.	Line	Y	y′	Equation	Cutting with sea level	Cutting with next following line
54.	d_{23}	131.4	—66.0	$y = 0.1778\ x — 66.0$	371	(486, +20.0)
55.	d_1	129.1	—64.2	$y = 0.1741\ x — 64.2$	369	(250, —21.0)
56.	d_{11}	127.0	—63.6	$y = 0.1717\ x — 63.6$	370	(200, —29.0)
57.	d_{12}	125.2	—63.2	$y = 0.1697\ x — 63.2$	372	(227, —25.0)
58.	d_{13}	123.2	—62.7	$y = 0.1675\ x — 62.7$	374	(176, —33.0)
59.	d_{14}	121.6	—62.4	$y = 0.1658\ x — 62.4$	376	(115, —43.0)
60.	d_{15}	119.1	—62.1	$y = 0.1632\ x — 62.1$	381	(250, —21.0)
61.	d_{16}	117.0	—61.5	$y = 0.1608\ x — 61.5$	382	(429, + 7.0)
62.	d_{17}	115.6	—60.6	$y = 0.1587\ x — 60.6$	382	(381, + 0.3)
63.	d	112.5	—59.0	$y = 0.1545\ x — 59.0$	382	(59, —50.0)
64.	d.	110.7	—58.9	$y = 0.1528\ x — 58.9$	385	(417, + 4.8)
65.	d..	109.0	—57.9	$y = 0.1504\ x — 57.9$	385	(182, —31.0)
66.	c_4	107.0	—57.5	$y = 0.1482\ x — 57.5$	388	(694, +45.0)
67.	c_{41}	105.5	—55.0	$y = 0.1446\ x — 55.0$	380	(645, +38.0)
68.	c_{42}	104.1	—53.0	$y = 0.1415\ x — 53.0$	375	(370, + 0.6)
69.	c_{43}	102.1	—52.0	$y = 0.1388\ x — 52.0$	375	(417, + 5.9)
70.	c_{44}	100.4	—51.0	$y = 0.1364\ x — 51.0$	374	(568, +26.0)
71.	c_{45}	98.0	—48.5	$y = 0.1320\ x — 48.5$	367	(640, +36.0)
72.	c_3	94.0	—43.0	$y = 0.1234\ x — 43.0$	348	(120, —28.0)
73.	c_{31}	91.5	—42.7	$y = 0.1209\ x — 42.7$	353	(316, — 4.5)
74.	c_2	88.5	—41.5	$y = 0.1171\ x — 41.5$	354	(517, +19.0)
75.	c_{21}	86.8	—40.0	$y = 0.1142\ x — 40.0$	350	(318, — 3.7)
76.	c_{22}	85.0	—39.3	$y = 0.1120\ x — 39.3$	351	(417, + 7.4)
77.	c_{23}	83.4	—38.3	$y = 0.1096\ x — 38.3$	349	(400, + 5.5)
78.	c_{24}	81.6	—37.3	$y = 0.1071\ x — 37.3$	348	(267, — 8.7)
79.	c_1	79.0	—36.5	$y = 0.1041\ x — 36.5$	351	(238, —12.0)
80.	c_{11}	77.2	—36.0	$y = 0.1020\ x — 36.0$	353	(150, —20.0)
81.	c_{12}	75.5	—35.7	$y = 0.1000\ x — 35.7$	355	(77, —28.0)
82.	c_{13}	74.0	—35.6	$y = 0.0987\ x — 35.6$	360	(111, —25.0)
83.	c_{14}	72.2	—35.4	$y = 0.0969\ x — 35.4$	366	(59, —30.0)
84.	c_{15}	70.4	—35.3	$y = 0.0952\ x — 35.3$	372	(158, —20.0)
85.	c	68.6	—35.0	$y = 0.0933\ x — 35.0$	375	(278, — 9.0)
86.	c.	67.1	—34.5	$y = 0.0915\ x — 34.5$	377	(278, — 9.0)
87.	c..	65.0	—33.5	$y = 0.0887\ x — 33.5$		(337, — 1.8)
88.	c...	63.0	—33.0	$y = 0.0865\ x — 33.0$		
89.	c::	60.0	—31.0	$y = 0.0772\ x — 31.0$		
90.	b	58.8	—20.5	$y = 0.0714\ x — 20.5$	287	(125, —12.0)
91.	b.	56.4	—20.2	$y = 0.0690\ x — 20.2$	293	(548, +18.0)
92.	b..	54.0	—17.9	$y = 0.0648\ x — 17.9$	276	(389, + 7.0)
93.	a_9	51.4	—16.5	$y = 0.0612\ x — 16.5$	270	(250, — 1.0)
94.	a_{91}	50.0	—16.1	$y = 0.0596\ x — 16.1$	271	(200, — 4.0)
95.	a_{92}	49.1	—15.9	$y = 0.0586\ x — 15.9$	271	(357, + 5.0)
96.	a_8	47.0	—14.9	$y = 0.0558\ x — 14.9$	267	(346, + 4.4)
97.	a_{81}	45.1	—14.0	$y = 0.0532\ x — 14.0$	263	(385, + 6.5)
98.	a_{82}	43.2	—13.0	$y = 0.0506\ x — 13.0$	257	(318, + 3.0)
99.	a_{83}	41.4	—12.3	$y = 0.0484\ x — 12.3$	254	(292, + 1.8)
100.	a_7	39.5	—11.6	$y = 0.0460\ x — 11.6$	252	(300, + 2.0)
101.	a_{71}	37.8	—11.0	$y = 0.0440\ x — 11.0$	250	(349, + 6.0)
102.	a_{72}	36.5	—10.3	$y = 0.0422\ x — 10.3$	244	(150, — 5.0)
103.	a_{73}	34.6	—10.0	$y = 0.0402\ x — 10.0$	349	(143, — 4.3)
104.	a_{74}	33.3	— 9.8	$y = 0.0388\ x — 9.8$	253	(188, — 2.5)
105.	a_{75}	31.8	— 9.5	$y = 0.0372\ x — 9.5$	256	(176, — 3.0)
106.	a_6	30.2	— 9.2	$y = 0.0355\ x — 9.2$	259	(150, — 4.0)

Nr.	Line	Y	y′	Equation	Cutting with sea level	Cutting with next following line
107.	a_{61}	28.3	— 8.9	$y = 0.0335\ x - 8.9$	266	(154, — 3.7)
108.	a_{62}	27.0	— 8.7	$y = 0.0322\ x - 8.7$	270	(100, — 5.5)
109.	a_{63}	25.0	— 8.5	$y = 0.0302\ x - 8.5$	281	(125, — 4.8)
110.	a_5	23.5	— 8.3	$y = 0.0286\ x - 8.3$	291	(188, — 3.0)
111.	a_{51}	22.0	— 8.0	$y = 0.0270\ x - 8.0$	296	(143, — 4.0)
112.	a_{52}	20.6	— 7.8	$y = 0.0256\ x - 7.8$	305	(182, — 3.0)
113.	a_4	19.6	— 7.6	$y = 0.0245\ x - 7.6$	310	(143, — 4.0)
114.	a_{41}	18.2	— 7.4	$y = 0.0231\ x - 7.4$	317	(91, — 5.3)
115.	a_{42}	17.1	— 7.3	$y = 0.0220\ x - 7.3$	332	(455, + 2.7)
116.	a_{43}	15.0	— 5.8	$y = 0.0187\ x - 5.8$	310	(333, + 0.4)
117.	a_3	13.3	— 5.1	$y = 0.0166\ x - 5.1$	307	(316, + 0.1)
118.	a_{31}	11.8	— 4.5	$y = 0.0147\ x - 4.5$	301	(63, — 3.6)
119.	a_{32}	10.1	— 4.4	$y = 0.0131\ x - 4.4$	336	(91, — 3.2)
120.	a_2	9.0	— 4.3	$y = 0.0120\ x - 4.3$	358	(0, — 4.3)
121.	a_{21}	7.9	— 4.3	$y = 0.0110\ x - 4.3$	391	(433, + 0.4)
122.	a_1	5.9	— 3.0	$y = 0.0080\ x - 3.0$	375	(273, — 0.8)
123.	a_{11}	4.0	— 2.4	$y = 0.0058\ x - 2.4$	414	(438, + 0.1)
124.	a_{12}	3.0	— 1.7	$y = 0.0042\ x - 1.7$	405	(467, + 0.3)
125.	a_{13}	2.0	— 1.0	$y = 0.0027\ x - 1.0$	370	(370, 0)
126.	a_0	0	0	$y = 0$		

3. A Curve Showing the Rise of Sea Level during the Melting of the Last Inland Ice.

In the present diagram, Pl. I, every raised shoreline level cuts the ordinate axis between the zero-line and the point (0.—99.7). Such a negative ordinate, —99.7 included, is supposed to represent the distance of the cutting level from the present sea level in the scale 1 : 1000. These ordinates, directly read from the diagram, have been inserted in the list of equations as the series y′ and are used for the drawing of the curve in Pl. II.

The seven uppermost sloping lines in the diagram were once disregarded because they were built on material not wholly to be trusted (4). But as such material was only used for fixing the three oldest lines, it was hardly quite right to reject all the seven lines on that account. If these lines are regarded as a whole it will be seen that most of the ordinates of their cutting points on the ordinate axis are increasing from —92 to —99.7 while the ordinates of all the younger lines are decreasing from —99.7 to zero. As these ordinates are supposed to indicate the distance from a former level of the sea to the present sea level, the increase of ordinates must denote a sinking of the sea level from —92 to 99.7 while the decrease of the ordinates of the younger lines denotes a rise of sea level from —99.7. Further is to be noted that the distance between the lines, especially between p and o^2 and o^2 and o^1, is so extraordinarily great that this tells of an opposite movement of sea and land — that the sea was sinking and the land rising at the same time. It, therefore, seems to be a fact that the land had reached its lowest stand and was rising while the sea still was sinking. But if so, it can in no way have been a rule.

In this connection it may be appropriate to draw attention to some observations made near Malmö, mentioned in Sveriges geologi page 187. Some strandmarks and depositions above the level of the Baltic Ice Lake are there reported.

In addition to the seven somewhat doubtful shorelines mentioned above there are 4 doubtful lines between c and b. The first two of them can be fairly well determined as the material is in some measure satisfactory, but the two last lines can only be drawn after an interpolation.

Interglacial shorelines have not been pointed out.

4. A Curve Showing the Rise of the Land at the Zero-Isobase of the n-Line.

While the eustatic movement of the sea level was the same everywhere on the earth, the movement of those parts of the earth's surface weighed down by ice caps was varying from one depression to another and from point to point within the same depression. The movement of the depressed land area within the Fennoscandian depression, therefore, can be regarded as a local phenomenon, independent of the movement of the sea surface. The movement of the land can thus be found by eliminating the contemporary movement of the sea. This can be done in the following ways:

I. If the equations of two consecutive lines are $Y = Kx + B$ and $y = K'x + B'$, they can be written:

$$Y - B = Kx$$
$$y - B' = K'x$$
$$Y - y - B + B' = (K - K')x$$

If $B = B'$, which means that the two lines, retaining their directions, are moved to pass through the same point of the ordinate axis, then the equation is

$$Y - y = (K - K')x.$$

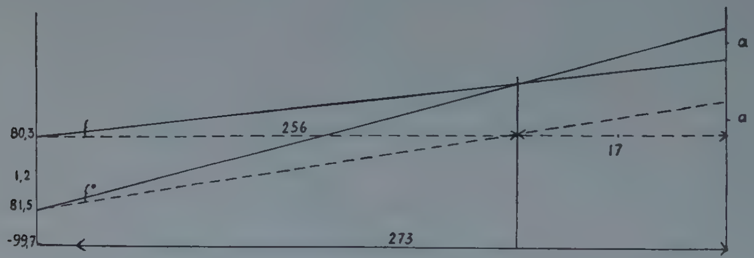
If one wishes to find the rise of the land at the zero-isobase of the n-line, then $x = 273$, and the ordinate difference $Y - y = a$ is the rise of the land between the two lines n and m at the said isobase. The formula is then: $a = (K - K')x$.

Ex. 1. $f^{\circ} : y = 0.2334\,x - 81.5$ $K = 0.2334$ $K - K' - 0.0047$
$f : y = 0.2287\,x - 80.3$ $K' = 0.2287$
$a = 0.0047 \cdot 273 = 1.3$

Ex. 2. $e : y - 0.2222\,x = 78.5$ $K = 0.2222$ $K - K' = 0.0056$
$d5 : y = 0.2166\,x - 76.7$ $K' = 0.2166$
$a = 0.0056 \cdot 273 = 1.5$

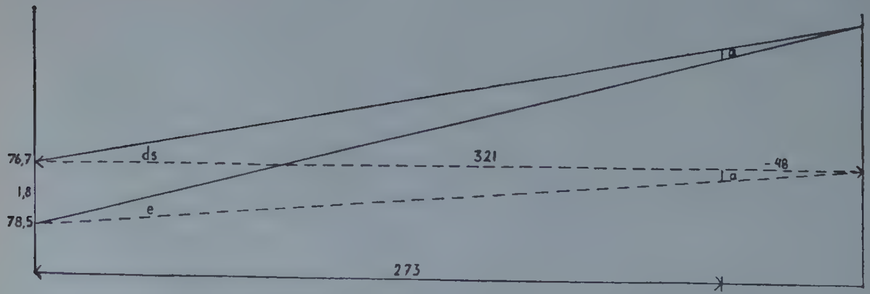
By means of the formula here used all values of *a* in the table on page 49 have bee ncalculated.

II. A more detailed method has been used in the two examp'es below, but it gives the same result. All the values are given correctly within ± 1 dm.



Ex. 1. $f^{\circ} : y = 0.2334\,x - 81.5$ $12000 : 47 = 256$ $\frac{a}{17} = \frac{1.2}{256}$
$f : y = 0.2287\,x - 80.3$ 273
$0.0047\,x = 1.2$ 17 $a = 0{,}1$

Sea risen 1.2
Land „ 0.1 more
1.3 in all



Ex. 2. $e : y = 0.2222\,x - 78.5$ $18000 : 56 = 321$ $\frac{a}{-48} = \frac{1.8}{321}$
$d5 : y = 0.2166\,x - 76.7$ 273
$0.0056\,x = 1.8$ -48 $a = -0.3$

Sea risen 1.8
Land „ 0.3 less
1.5 in all

Data for drawing of the curve of land rising at the zero-isobase of the *n*-line, Pl. II.

The calculated values of *a* stand in the table with a + in front, and the numbers of the shorelines are to be plotted from y = —99.7 upwards.

n	0	h1	24.2	d3	46.1	c42	61.3	c:	76.4	a62	91.2
	+ 1.3		+ 1.1		+ 0.8		+ 0.7		+ 2.5		+ 0.5
m	1.3	h11	25.3	d31	46.9	c43	62.0	c:	78.9	a63	91.7
	+ 1.4		+ 1.0		+ 1.2		+ 0.7		+ 1.6		+ 0.4
L2	2.7	h	26.3	d32	48.1	c44	62.7	b	80.5	a5	92.1
	+ 1.4		+ 1.4		+ 0.6		+ 1.2		+ 6.7		+ 0.4
L1	4.1	g4	27.7	d2	48.7	c45	63.9	b	81.2	a51	92.5
	+ 1.9		+ 1.0		+ 0.4		+ 2.3		- 1.1		+ 0.4
L	6.0	g3	28.7	d21	49.1	c3	66.2	b:	82.3	a52	92.9
	+ 1.6		+ 0.7		+ 0.7		+ 0.7		+ 1.0		+ 0.3
k2	7.6	g2	29.4	d22	49.7	c31	66.9	a9	83.3	a4	93.2
	+ 1.1		+ 0.6		+ 1.5		+ 1.0		+ 0.4		+ 0.4
k1	8.7	g1	30.0	d23	51.3	c2	67.9	a91	83.7	a41	93.6
	+ 1.0		+ 0.7		+ 1.0		+ 0.8		+ 0.3		+ 0.3
k	9.7	g°	30.7	d1	52.3	c21	68.7	a92	84.0	a42	93.9
	+ 1.3		+ 1.3		+ 0.7		+ 0.6		+ 0.8		+ 0.9
I4	11.0	g	32.0	d11	53.0	c22	69.3	a8	84.8	a43	94.8
	+ 1.5		+ 0.8		+ 0.5		+ 0.7		+ 0.7		+ 0.6
I3	12.5	f2	32.8	d12	53.5	c23	70.0	a81	85.5	a3	95.4
	+ 1.6		+ 1.1		+ 0.6		+ 0.7		+ 0.7		+ 0.5
i2	14.1	f1	33.9	d13	54.1	c24	70.7	a82	86.2	a31	95.9
	+ 1.6		+ 2.1		+ 0.5		+ 0.8		+ 0.6		+ 0.4
i1	15.7	f°	36.0	d14	54.6	c1	71.5	a83	86.8	a32	96.3
	+ 1.4		+ 1.3		+ 0.7		+ 0.6		+ 0.7		+ 0.3
i	17.1	f	37.3	d15	55.3	c11	72.1	a7	87.5	a2	96.6
	+ 0.7		+ 1.8		+ 0.7		+ 0.5		+ 0.5		+ 0.3
h4	17.8	e	39.1	d16	56.0	c12	72.6	a71	88.0	a21	96.9
	+ 1.5		+ 1.5		+ 0.6		+ 0.4		+ 0.5		+ 0.8
h3	19.3	d5	40.6	d17	56.6	c13	73.0	a72	88.5	a1	97.7
	+ 1.1		+ 0.8		+ 1.1		+ 0.5		+ 0.5		+ 0.6
h31	20.4	d51	41.4	d	57.7	c14	73.5	a73	89.0	a11	98.3
	+ 0.9		+ 1.7		+ 0.5		+ 0.5		+ 0.4		+ 0.4
h32	21.3	d4	43.8	d	58.2	c15	74.0	a74	89.4	a12	98.7
	+ 1.0		+ 0.6		+ 0.7		+ 0.5		+ 0.4		+ 0.4
h33	22.3	d41	43.7	d	58.9	c	74.5	a75	89.8	a13	99.1
	+ 0.5		+ 0.8		+ 0.6		+ 0.5		+ 0.5		+ 0.7
h2	22.8	d42	44.5	c4	59.5	c	75.0	a6	90.3	a°	99.8
	+ 0.8		+ 0.5		+ 1.0		+ 0.8		+ 0.5		
h21	23.6	d43	45.0	c41	60.5	c:	75.8	a61	90.8		
	+ 0.6		+ 1.1		+ 0.8		+ 0.6		+ 0.4		
h1	24.2	d3	46.1	c42	61.3	c:	76.4	a62	91.2		

5. The Movement of Sea and Land at the Danish Sounds and in the Baltic Basin.

Tanner has in his "Studier över Kvartärsystemet i Fennoskandias Nordliga Delar IV 1930, "pages 389—394 coordinated the old Danish shore-lines in Vendsyssel with the old shore-lines in Northern Norway and Finland, and he found that the oldest Danish shore-lines were of the same age as the Norwegian lines *i* and *k,* in particular *i.* The present author has made a similar attempt and with nearly the same result. I found the oldest Danish shore-line to be *i2,* and below this line many of the younger lines seemed to be identical with lines in the Norwegian diagram. The line *i2* therefore, very likely, represents the upper marine limit, and the course of its zero-isobase is largely parallel to that of the n-line at a distance of only 5 km to the right, and mostly coincides with a zero-line in a map by E. Granlund 1936 in Sveriges geologi page 179.

As the distance between the two zero-isobases of n and i2 is so small, it must be allowable to use the calculated values for the zero-isobase of n instead of that of i2. These calculated values will no doubt give a fairly good approximation and be a measure of the rise of the land at the Danish Sounds.

The curve of the rise of the land is sketched in Pl. II b. Along the zero-isobase of n both sea and land had risen from their lowest stand —99.7 to the present sea level. West of this line the land surface has risen less than 99.7 m, and there transgressions and inundations were more or less frequent according to the distance from the zero-isobase. On the north-east side of it the rise of the land was greater than 99.7 m and was increasing according to an arithmetic progression. There regressions took place. What here is said only applies to the rise of sea and land as a whole, but both sea and land were rising at the same time, each in its own way. The actual transgressions and regressions, therefore, came out as a result of these movements. In the sequel, however, no details will be entered upon.

How the two curves *a* and *b* in Pl. II have been found has been dealt with earlier. It will be seen that the two curves are steadily rising, but with varying velocity. It is possible that the rise of the sea has been at times interrupted by lesser sinkings, but this has not been shown in the diagram. Regarding the rise of the land it is less probable that it has been interrupted, for no standstill or sinking has been pointed out. All told, the land surface seems to have had a more even rate of motion than the surface of the sea.

The dotted curve *c* Pl. II running parallel to *b* in a distance of 18 mm shows the rise of the bottom of Darsser Schwelle. It is supposed that no sea water could enter the Baltic Basin through the Danish Sounds if this bottom was laid dry. According to Pl. II the bottom of D. Schw. was below the sea level during the first part of the rising period. At the start when the n-line was engraved the depth was about 18 m, but from this primary stand the depth was steadily decreasing between n and g. It was the time of the ice lakes. Between the levels g and c4 the curve *c* was coinciding with the eustatic curve *a* for about 1900 years. The bottom of Darsser Schwelle lay in the sea level. The sea water could not pass the Danish Sounds. It was the time of the Yoldia Sea and the Ancylus Lake. The Yoldia Sea had not any passage through the Danish Sounds to the ocean, and the level of the Ancylus Lake seems to have been situated near the sea level and only so much above it as was fixed by the afflux of fresh water and the form and size of the outlet.

But from c4 about 8200 years ago a strong rise of the sea level set in, and it continued with increasing velocity until the depth at Darsser Schwelle was about 9 m. Sea water penetrated into the Baltic Basin, and the Ancylus Lake was little by little converted into a brackish sea. The rise of the sea level was relatively strong between c4 and c3 (about 9 m in 660 years), but between c3 and c land and sea had practically the same velocity, and therefore the depth at Darsser Schwelle was nearly constant for a long time (about 975 years). That was the first half of the Atlantic period.

From c started a new and strong rise of the sea level, known as the Tapes-transgression. This rise was followed by a strong increase of salt water, and the former brackish sea was then converted to the salt Littorina Sea. The quick rise of the sea level in the Baltic Basin stopped at the shoreline b, the Littorina Limit.

Between c and b there are 4 lines not satisfactorily determined on account of insufficient material. This chiefly applies to the lines c.: and c:: which are inserted after a somewhat doubtful interpolation. None of these are presumed to belong to the Tapes level. But to this level, most likely, are to be ranked b. and b:, and probably a91 and a92 which join the b-level below 9 m where accurate measurements are very difficult to get, because more levels are coinciding there.

According to Plate II the eustatic curve *a* was drawing near the land rising curve *b* at the b-line. From b to a8 *a* is still below *b*, but between a8 and a63 *a* is above *b* with a maximum at a7. From a5 to a° the eustatic curve *a* was once more below *b* with a minimum at a21. At maximum *a* was 1—2 m above *b*, at minimum 1—2 m below, a difference about 3 m. This is not much, but in spite of that, it seems to have brought about a decrease of the saltness of the Littorina Sea which little by little was altered to the more brackish Limnæa Sea.

For showing how *a* and *b* might go together with the general view, given in Sveriges geologi, page 236, on the late-quaternary period, is borrowed what was of peculier interest from this survey: From Sernander The Climatic Periods, from Munthe The Development of the Baltic and from De Geer The Geochronological Periods. Besides this is added the age of some shorelines, calculated by Arne Grønlie.

Lack of recent Danish and Swedish literature prevent me from treating more in detail what has been touched upon above. I must therefore only confine myself to point out what can be read directly from the present diagrams.

6. On the Formation of Strandflats, Shore-lines and the Continental Shelf.

Along the western and northern coasts of Norway there is a flat lowland between the steep rocky wall of the mountains and the present sea shore, and there are many low islands at the same levels. It is these flat lowlands and the bottom of the shallow sea off the shore that has been called the strandflat. But farther off the coast is a new level between 100 and 400 m. This level is the Continental Shelf.

The strandflat was for the first time described and named by Dr. Reusch in a paper 1894 as a new trait in the geography of Norway. Since then many others have surveyed and described it, among which may be named Andreas M. Hansen, Rekstad, J. H. L. Vogt, Th. Vogt, Nansen, Holtedahl, Undås, Sahlstrøm, Ahlmann. Along the northern coast of our country the present writer has also had occasion to see it.

As a result of the investigations that have been carried out the material is fairly great. The "Strandflat and Isostasy" by Nansen must especially be mentioned as a highly interesting and valuable work.

According to Nansen the strandflat consists of three levels, one level below the sea and two above it. Along the coast of Skagerak the strandflat is poorly developed, and between Lista and Jæren it is narrow but strongly engraved in solid rock. On the northern part of Jæren its breadth is considerable, and its upper level is about 30 m above the sea. Between Stavanger and Stad it is well developed especially on the islands. From Stad northwards its breadth is increasing to off the mouth of the Trondhjemsfjord where it comprises all Smøla and Frøya and a great part of Hitra and a greater part of the sea bottom northwest and north of these islands. The uppermost level lies about 30 m above sea level. Farther northwards to Vikna islands the strandflat is finely developed along the front of the steeply ascending mountains and with a submarine part off the coast. A great part of Vikna is strandflat ascending to 30 m, and on the western side of these islands is a wide submarine strandflat.

In Helgeland the strandflat is very broad, from the mainland to the outer edge above 40 km. A multitude of islands and islets are levelled to strandflat, and farther out to sea is a vast number of skerries and submarine rock ledges to be seen when the sea is breaking. Among the many islands is often to be seen that the strandflat is alike developed on the lee side and the weather side showing it to be the work of the frost; the frost has broken the rock, and the waves have washed the loose material away. The highest level of the strandflat is but slightly developed in Helgeland. It is the two lower levels that have the greatest extension.

An isolated group of islands is Træna, standing on a great and uneven submarine socle. Oxaal found there an uppermost level of the strandflat 40—45 m a. s. l., which is the top level of some islands of medium size in the group. On Sanda the highest flat ground I found was 36 m a. s. l. A lower level was found 8 m a. s. l.

In Salten and Lofoten the strandflat is relatively narrow but well developed. The low peninsula at Bodø is for the most part a strandflat between 10 and 20 m a. s. l., now covered with the ground moraine of the last inland ice and postglacial sediments. Værøy and Røst stand each on its respective submarine socle. Røstlandet, the largest island in the Røst group is a strandflat 11 m a. s. l. On its northwestern side is a broad submarine strandflat. On the eastern side of Værøy is a strandflat at a level like that of Røstlandet, and on the north-western side is a broad submarine strandflat. The rocks on these islands were more easily broken down than the rocks on the other Lofoten islands, and therefore the strandflat is more ripe there.

The strandflat is imperfect on the western side of Moskenesøy and Langøy, but there is strandflat round Hadseløy and on the eastern side of Langøy. On Andøy a greater part of the lowland is strandflat. The hight is about 30 m, but there is also a level 8 m a. s. l. Farther to the north there is still a strandflat, but it passes away towards Vest-Finnmark. In Finnmark the strandflat is rather faintly and imperfectly developed.

It can generally be said that the strandflat is so covered with ground moraine that it is difficult to fix its real level. Therefore levellings are but little better than aneroid measurements. The top level is often stated to be 30 m, but also 40—50 m has been reported, and on the southern end of Landego a flat is found 100 m a. s. l., supposed to be levelled by abrasion. Undås and others have even mentioned hights of 120 m. Even less fixed is the intermediate level. The upper part of the submarine strandflat is bounded upwards by the present shoreline, but its lower limit is not so well fixed. There seems to be an even transition from the strandflat to the uppermost level of the continental shelf. A tripartition of the level of the strandflat, therefore, seems to be somewhat dubious.

There is a difference of opinions on how and when the strandflats were formed, but most of the opinions on this subject join in declaring the wave action as essential. Reusch explained the strandflat as formed by wave action chiefly during the Tertiary period on a slightly indented coast, supported by weathering and erosion, continuel during that part of the ice age when the coast land was not yet covered by an ice sheet. Andreas M. Hansen was of opinion that the strandflat had been formed during the later part of the first great ice age partly by wave erosion and partly by the scouring of the drifting ice along the shores of the sounds. The coast had then already been dissected by numerous fjords and channels. The glacial erosion has also been of much importance. De Geer and Holtedahl maintained that the strandflats had been formed by dislocations. J. H. L. Vogt was of the opinion that the strandflat had been formed by wave action along a practically straight coast after the Jurassic dislocation on Andøy, continued till the beginning of the first ice age. The idea of wave action is maintained by Rekstad, and Sahlström, Helland meant that the strandflat and the low skerries were formed by erosion of the inland ice. Ahlmann had not found any strandflat along our coast. The flats called so were base-levelled "solely by subaérial denudation, in some places assisted by glacial erosion". (5, p. 7). Nansen maintained that "the strandflat had been developed chiefly during interglacial periods with cold climates, and especially during the very cold time preceding each glacial period, and during its first part, before the outer coast was covered by the inland ice, and as long as the level of the shore-line still remained nearly stable." (5, p. 47). Nansen laid strong stress on the erosion by frost in the strand level as a rock breaking power. Undås maintains that the strandflats must have got their final forming during the last ice age, before the land was inundated by the last inland ice (7).

Besides the explanations and views mentioned above there can be added a new view got at by studying Plate III. As this view does not coincide entirely with anyone of the former views, it will be the subject of a closer account on the pages below.

As formerly mentioned the sloping lines in Plate I are not shore-lines, but the flats in which the shore-lines were engraved when still coinciding with the sea level. The points entered in Plate III are the cutting points between a sloping line and the next following in the diagram, Plate I. As the angles between these lines are very small, the coordinates of the points have beeen found by calculation, because they could not be taken out of the diagram directly with sufficient accuracy. The abscissæ have been calculated with an exactness of the nearest whole number, the ordinates a little more exactly.

Since the sloping lines in the diagram really are flats a "point" is in reality the cutting line between two consecutive flats. This cutting line lay of course always in the sea level and was the real shore-line which had been more or less in motion since the ocean came into being. It is the cutting line between the sea level and the land with the youngest of the two flats always being identical with the sea level and a raised line forming a diminutive angle with it. From the stand of the sea level at — 99.7 till now the sea and the depressed part of Fennoscandia have been steadily rising, but not with the same velocity.

If the sea was more quickly rising than the land, the cutting line would be moving to the right till land and sea got the same velocity, but if the land did rise more quickly than the sea, the cutting line would move to the left. The movement was for the most part horisontal, because the mean rising of the sea was hardly more than 1 m in 120 years. For a short time the cutting line was relatively at rest by passing from moving to the right to moving to the left. It is these relative stopping places which are entered in Plate III.

During nearly 12000 years this movable cutting line — the real shoreline — has been moving forwards and backwards and must during that time have done a mighty work of abrasion from near 100 m below the present sea level to about 45 m above it. This work has been done just within the levels which have been estimated as belonging to the strandflat. It is therefore reason to believe that the strandflat for a great part was formed by abrasion. But the rising of the land after the last ice age was of course only the last working period. Similar work must have been done during the first part of every interglacial period, and that with greater amplitudes both above and below sea level. If so it will explain why flats abraded by the sea are to be found 100 m and more above the present sea level. In our country only one interglacial period is known with certainty, but as there in Denmark, Germany, and Poland are two and in the Alps even three interglacial periods, it is likely that our country as well may have had the same number of interglacial periods.

Simultaneously with the abrasion of the strandflats the shore-lines were engraved. Each time when the moving shore-line changed its direction of movement and was in relative rest to the land surface, one of the raised shore-lines was engraved. To the 115 points on Plate III, which show the relative stopping places of the moving line, there are 115 corresponding shore-lines engraved. As the angles between the raised levels are small, never above three seconds, the effect of a relative stop is far-reaching, so that a good shore-line was engraved for many km on both sides of the point in question. Though the odds are that a greater part of the shore-lines has been formed in this way, not a few shore-lines have been formed as storm-lines under gales blowing on an exposed shore. The seven uppermost lines in the diagram Plate I are supposed to have been formed in that way.

The engravings of shore-lines were only small matters compared with the abrasion of the strandflats, and the forming of a shore-line only lasted for a relatively short time. 12000 years shared among 115 shore-lines give 104 years per each shore-line, but during a greater part of this time the abrading line was washing the space lying between two shore-lines. Therefore the time occupied in forming a shore-line could only have been a fractional part of the 104 years.

It has been pointed out that the last but one ice age, our great ice age, was superior to the last ice age, at least larger by one half. One must take it for granted that also the depth of the depression and the sinking of the sea level were correspondingly greater. A sinking of the sea level 150—200 m or more was very probable. But if so, then the abrasion during the last interglacial period must have reached down below the upper level of the continental shelf. If there were three ice ages and two interglacial periods, therefore two more working periods, then there was time enough for a strong abrasion in and below the said depth. But as it was, also other forces than wave action and erosion by frost must be considered when the forming of the continental shelf is to be reviewed. Both the strandflat and the continental shelf have at least been two times overflowed by an inland ice during the ice ages. Even if it is to be assumed that the inland ice had not any great eroding power in its periferic part, it is, however, probable that it was of some importance for the forming of the strandflat and among other things may have brought about that the elevations of levels are so variable. As for the share the inland ice may have had in the forming of the continental shelf, it most probably did consist more in a deposition of loose material than in erosion. It must be supposed that on the continental shelf there has been deposited two or three ground moraines with a thickness nearly like that of the ground moraine in Central Europe. A systematic investigation of the loose material on the continental shelf has not yet been carried out in our country; in some places, however, loose material like that in the ground moraine on land has been taken up by soundings and dredgings.

According to the diagram the strandflats and shore-lines have been formed in interglacial and late-glacial periods as long as both land and sea were rising after the last submersion. How far strandflats and shore-lines were formed during the last parts of the interglacial periods of this the diagrams do not give any information. The temperature was falling off, and the erosion by frost increasing, and therefore a strong abrasion along the shores must have taken place, but shore-lines do not seem to have been developed or, if formed not preserved. They must have been overflowed by the sea or blotted out by the ice sheet that was drawing near. On the other hand inter-

glacial shore-lines formed during a rising period of land and sea can be found in hights above the upper boundary of the last ice sheet, but sure shore-lines of interglacial age have not yet been reported in Norway.

Norsk resymé.

I 1940 fikk nærværende forfatter trykt en avhandling i Norsk geologisk Tidsskrift, Bind 20, med titel On the Traces of the Ice Ages in Northern Norway. Denne avhandling var ment å være en foreløpig meddelelse da materialet var mindre grundig gjennomarbeidet. Det som her framlegges er en helt ny bearbeidelse hvor feilene fra før er søkt rettet og materialet er mer utnyttet. Da det i okkupasjonstiden var vanskelig å komme ut for å samle nytt materiale, er det for det meste materialet fra før som jeg har hatt til fornyet gjennomgåelse.

1. *Materialet og bemerkninger til dette.*

På sidene 1—13 er materialet innført. Det er innsamlet på vestkysten av Nord-Norge mellom Hammerfest og Bindalen. På grunn av den sterke omplasering av lokalitetene som var nødvendig, har jeg funnet det riktig å ta det med i sin helhet. Av nytt materiale har jeg lånt 10 nivellementer av Undås fra Vest-Finnmark, nemlig numrene: 2, 6, 7, 15, 18, 22, 57, 61, 65 b og 114, og 8 av A. Grønlies nivellementer fra Beiarn, nemlig numrene: 341, 350, 353, 360, 362, 363, 371 og 375.

2. *Strandlinjediagrammet og linjenes ligninger.*

3. *Havstigningskurven.*

Listen over linjene i strandlinjediagrammet omfatter 126 linjer mer eller mindre godt bestemt. I denne liste er også innført ligningene for disse linjer. Det er brukt et rettvinklet koordinatsystem med diagrammets 0-linje som x-akse. Som y-akse er brukt en vertikal linje gjennom skjæringspunktet mellom n og m. Denne linje begrenser diagrammet til venstre. Den vertikale linje som begrenser diagrammet til høyre ligger 1110 mm fra y-aksen. Disse to linjer, $x = 0$ og $x = 1110$, skjæres av alle skrålinjer i diagrammet, og ordinatene for disse skjæringspunkter kan leses av i diagrammet med en nøyaktighet av 0.1—0.2 mm. Ved hjelp av disse ordinater kan ligningene for alle disse linjer finnes som vist på side 43. Av størst interesse er ordinatene til venstre, da de direkte viser hvor dypt under den nåværende havflate havnivået sto dengang vedkommende skrålinjer ble inngravet. Tallrekken y′ viser lengden av disse ordinater.

De øverste 7 linjer i diagrammet er bygget på usikkert materiale, og især er de tre eldste tvilsomme, da det til deres bestemmelse er tatt med materiale fra Novaja Semlja. Forrige gang da materialet var under behandling, ble de derfor satt ut av betraktning, men det var neppe helt riktig. Da nå litt nytt materiale er kommet til, er de derfor tatt med. De kan ikke være interglaciale da de alle ligger under øverste grense for siste innlandsis. De må derfor være senglaciale. De tre øverste skjærer negativ y-akse i samme punkt hvilket tyder på en stilstand i havnivåets bevegelse, og da aksesnittenes ordinater tiltar i lengde fra —92 til —97.7 antas det å bety at havnivået har sunket. For alle de yngre linjer derimot avtar disse ordinaters lengde fra linje til linje som tallrekken y′ viser, fra —99.7 til 0.

I Pl. II er havstigningskurven tegnet inn ved å avsette tallene i y′ nedover fra x-aksen.

Det kan bemerkes at linjene nr. 84 og 85 er mindre godt bestemt og linjene 86 og 87 er inntegnet etter en tvilsom interpolasjon.

4. *Landstigningskurven for n-linjens 0-isobase.*

Stigningen av hav og land kan ansees å være stort sett uavhengig av hverandre. Mens havstigningen må antas å ha vært den samme over den hele jord, forandret landstigningen seg fra sted til sted innen en depresjon og fra en depresjon til en annen. Derfor kan virkningen av havflatens bevegelse elimineres ved å flytte to på hverandre følgende linjer slik at de skjærer hverandre i samme punkt på y-aksen uten at vinkelen mellom dem eller deres retning forandres. På side 47 og 48 er vist hvorledes ligningene for linjene håndteres til en får en formel hvorved avstanden mellom linjene kan beregnes. Det er også vist ved to eksempler hvordan man på en annen måte kan komme til det samme resultat uten å bruke den nevnte formel. Ved å gå fram på en av disse måter er landstigningskurven for n-linjens 0-isobase funnet, den strekete kurve *b* i Pl. II. På samme måte kan stigningen av landet i hvilket som helst punkt innen en depresjon beregnes, når strandlinjenes ligninger er gitt.

5. *Bevegelsen av land og hav ved de Danske sund og i Østersjøbekkenet.*

Hvordan de ovennevnte kurver svarer til bevegelsen av land og hav ved de danske sund er her vist ved å betrakte stigningen av bunnen av Darsser Schwelle som nå ligger 18 m under havflaten. I samme dybde under havflaten lå bunnen av Darsser Schwelle også den gang n-linjen ble inngravet, men ifølge diagrammet steg landet hurtigere enn havet, og dybden over Darsser Schwelle ble derfor stadig mindre. Da linjen h ble inngravet var dybden bare 5 m, under linjen g 1 m og under f′ var den kommet på 0. Det var de isdemte sjøers tid. Fra f′ til c4 falt kurven for Darsser Schwelle sammen med havstigningskurven. De danske sund var stengt, så intet saltvann kunne trenge inn i det baltiske bekken. Det var Yoldiahavets og Ancylussjøens tid. Etter c4 begynte havet å stige hurtigere enn landet, og ved c3 var dybden over Darsser Schwelle blitt 9 m. Fra c3 til c steg land og hav omtrent like hurtig, så dybden holdt seg på ca. 10 m. Saltvann kunne i løpet av dennne tid trenge inn i Ancylussjøen og gjøre den om til en brakkvannssjø. Mellom c og b var det en stigning av havet på ca. 15 m. Det var Tapes (littorina) transgresjonen. Dybden over Darsser Schwelle var nå blitt ca. 17 m, og saltmengden steg ytterligere i dette innhav, Littorinahavet. Mellom b og a5 hadde havstigningen en liten overvekt så havnivået var litt høyere enn nå, men etter a5 har havnivået litt etter litt nærmet seg det nåværende. Det var Limnæahavet.

6. *Om dannelsen av strandflater, strandlinjer og den kontinentale plattform.*

Ved strandflate forståes de flater som forekommer mellom fjellfoten og den nåværende strand og på øyene langs kysten. Dertil kommer en undersjøisk flate fra stranden til henimot 100 m dyp. Mange har undersøkt den og skrevet om den. Mest grundig i behandlingen av strandflaten er Nansen som i boken "Strandflat and Isostasy" har lagt til rette et stort materiale. Et øverste nivå ligger mest i en høyde av 20—30 m. Et nivå under dette er mindre godt bestemt.

Ifølge Nansen er strandflaten langs Skagerak lite framtredende. Mellom Lista og Jæren er den smal i fast berg ca. 20 m o. h. På Jæren og nordover til Stad er den godt utviklet, især på øyene.

Mellom Stad og munningen av Trondheimsfjorden tiltar den meget sterkt i bredde, så den omfatter hele Smøla og Frøya og en stor del av Hitra. Den smalner av nordover til Vikna. På Helgeland er den meget bred og strekker seg langt til havs. I Salten er den noe ujevn og smal. Det samme er tilfelle i Lofoten. På Andøya har strandflaten en stor utstrekning, men ellers taper den seg nordover, og i Finnmark kan den knapt nok påvises.

Mange har forsøkt å finne ut når og hvorledes strandflaten er blitt formet, og de fleste synes å være enige om at bølgeslaget har vært en viktig faktor, men ut over dette går meningene langt fra hverandre. Nansen har i den nevnte bok gjort nokså detaljert rede for de forskjellige meninger og synspunkter, og det skal derfor ikke gjentas her, men da det finnes en ny måte å se de nevnte spørsmål på som ikke faller sammen med noen av de andres, skal jeg nedenfor gjøre rede for dette.

I Pl. III vises skjæringspunktenes koordinater for to på hverandre følgende linjer. Abscissene er beregnet med en nøyaktighet av nærmeste hele tall, ordinatene litt nøyaktigere. Tenker man seg nå land og havflate samtidig i bevegelse, vil også disse punkter komme i bevegelse.

Da skrålinjene egentlig er nivåflater, er det som hittil har vært kalt et »punkt« i virkeligheten skjæringslinjen mellom to på hverandre følgende flater. Denne skjæringslinjen lå selvfølgelig alltid i havnivået og var den virkelige strandlinje. Steg nå havflaten hurtigere enn landet, ville skjæringslinjen bevege seg til høyre. Steg derimot landet hurtigere enn havet, beveget skjæringslinjen seg til venstre. En kort stund var skjæringslinjen i relativ ro ved overgang fra bevegelse til høyre til bevegelse til venstre. Det er disse relative stoppesteder som er inntegnet som punkter i Pl. III. Bevegelsen var vesentlig i horisontal retning, da havet bare steg —99.7 m i ca. 12000 år): 1 m i 120 år.

I løpet av ca. 12000 år har således den bevegelige skjæringslinje — den virkelige strandlinje — kjørt fram og tilbake og må i denne tiden ha utført et stort abrasjonsarbeid fra —99.7 under havflaten til ca. 45 m over denne. Dette arbeid er utført nettopp innen de områder som regnes å høre til strandflaten, og det er derfor all grunn til å tro at strandflaten er blitt formet ved denne abrasjon. — Men stigningstiden etter siste istid var selvfølgelig bare siste arbeidsperiode. Lignende arbeid må ha vært utført i alle interglacialtider og det med større amplituder både over og under havnivået. Dette forklarer hvorfor det finnes abrasjonsflater i større høyde enn 45 m, like opp til 100 og 120 m. I vårt land er bare påvist 2 istider og 1 interglacialtid, men da det i Mellomeuropa er påvist 3 istider og 2 interglacialtider, må det antas at det har vært like mange hos oss, kanskje 4 istider og 3 interglacialtider som i Alpene.

Samtidig med abrasjonen av strandflatene ble strandlinjene i marken inngravet. Hver gang den bevegelige strandlinje skiftet bevegelsesretning og altså lå i ro i forhold til landet, ble 1 av de hevede strandlinjer inngravet. Til de 115 punkter som angir beliggenheten av de relative stoppesteder som den bevegelige strandlinje hadde, svarer 115 inngravede strandlinjer. Disse siste står i samme forhold til den bevegelige strandlinje som et fotspår til foten. Da vinklene mellom linjene, strandlinjenivåene, er meget små, høyst 2—3 buesekunder, forklarer det hvorfor en strandlinje kan være nokså sterkt inngravet selv om avstanden fra et relativt stoppested var stor.

Det er på denne måte jeg tenker meg at strandflater og strandlinjer er blitt til. Selvfølgelig var frostsprengningen viktig, idet den sprengte berget så bølgedraget så meget lettere kunne få tak i løsmaterialet og føre det bort. Lokalt kan nok strandlinjer oppstå under pålands-storm, men det er unntagelser, og serier av strandlinjer kan ikke oppstå på denne måte.

Inngravingen av strandlinjene var bare småting mot abrasjonen av strandflatene. 12000 år fordelt på de 115 strandlinjer blir gjennomsnittlig 104 år pr. strandlinje, men i en større del av den tiden var den abraderende linje i bevegelse og vasket mellomrommene mellom strandlinjene. Derfor var den tid som gikk med til inngravingen av selve strandlinjen i marken bare en brøkdel av de 104 år.

Sammenlignes de to kurver i Pl. II, vil det sees at landstigningskurven har et roligere forløp enn havstigningskurven. Landet må derfor ha steget med jevnere hastighet enn havflaten, uten stans eller tilbakeslag. Stigningen av havflaten var derimot mer variabel med flere perioder nærmest med stillstand. Noen senkning er ikke påvist.

Den kontinentale plattform antas dannet delvis ved abrasjon i interglacialtidene og delvis ved iserosjon under istidene og ved påfylling av løsmateriale, bl. a. to bunnmorener.

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PLATES

Pl. I.	Diagram of the shorelines in Northern Norway.
Pl. II a.	A curve showing the stand of the sea level while the shorelines were engraved during the melting period of the last inland ice.
Pl. II b.	A curve showing the rise of the land at the zero-isobase of the n-line.
Pl. II c.	A curve showing the rise of the bottom of Darsser Schwelle. It runs parallel with II b, 18 m below.
Pl. III.	A diagram showing the cuttting points between consecutive lines. Ex. n—m, m—l″, l″—l′ etc.

INVESTIGATIONS IN THE CRYSTAL CHEMISTRY OF SILICATES

III. The Relation Haematite — Microcline.

BY

IVAN TH. ROSENQVIST

Abstract. The relation between haematite and potash feldspar is discussed. These parageneses are often encountered in Norway. The solubility of Fe_2O_3 in microcline in solid state is determined by means of radioactive iron (fig. 5.) The solubility is normally low. It is concluded that e. g. the aventurine feldspar originally crystallized from a magma, poor in aluminum or rich in alcali. Thus the feldspars became rich in iron. A subsequent aluminum metasomatism replaced the iron atoms in the feldspar lattices. The iron thus expelled, formed the iron oxide lamellae in and between the feldspar crystals.

Pegmatites with microcline quartz and haematite as main constituents are rather frequent among the rocks of the Norwegian mountain chain. I found numerous pegmatites of this kind during my field work in the area between Opdal and Lesja. Rutile is often found as a minor constituent in them. The haematite occurs generally as plates, 0.5—2 mm thick, between the feldspar crystals. The microcline of the pegmatites is mostly light reddish, and contains very rarely inclusions of haematite or other dark minerals.

Also in the pre-Cambrian pegmatites in Østfold, in the Kongsberg—Bamble formation and in the Telemark formation similar parageneses are encountered. But these pegmatites from Southern Norway generally carry muscovite, biotite and a great variety of other minerals, also minerals containing Fe.

It seems to be a general feature that the feldspar minerals have only very slight iron content although minerals containing iron either as oxides or as silicates, are frequent in the rock. Chemical analyses of these feldspars often give an iron content as low as 0.01 % Fe_2O_3. It is, however, possible that the real content is still lower, as the microscopical examination unveils fine inclusions of dark minerals in the feldspar. The true iron content can consequently not be determined merely through a chemical analysis of a cleavage piece of the feldspar.

In the rocks of the Oslo-region, nearly opaque feldspar filled with fine dust of iron ore minerals is frequent. According to R. Selmer-Olsen (1): microcline crystals of a deep wine reddish colour are frequent in the breccia of the Kongsberg—Bamble formation. The colour is caused by a nearly sub-microscopical dust of haematite. He interprets these crystals as formed by late hydrothermal activity in the fault zones.

The two syenite varieties, tønsbergite and larvikite are nearly identical, both as to mineralogical and chemical composition. The feldspar from the tønsbergite is deep-red coloured from fine inclusions of iron oxide, whereas the feldspar from the typical larvikite is a dark labradorizing cryptoperthite.

The aventurines are a well known group of feldspar containing haematite. They were much used as cheaper gem stones. In Norway oligoclase aventurines are known from localities in the Kongsberg—Bamble formation. Olaf Andersen (2) has examined aventurines both as to their optical and thermical properties. The minerals examined came from localities in Norway, USA and Canada and included both plagioclases and potash feldspar. I summarize his results as follows.

The ferric iron primarely occurred in solution in the feldspar crystals, either as a surplus of Fe_2O_3 or as a dissolved compound of ferric iron. Due to a change in the equilibrium conditions after the crystallization, the Fe_2O_3 was expelled and formed small haematite lamellae in the feldspar crystals. This change was mainly a change in temperature. The lamellae crystallized along certain structural planes, and Andersen has identified several of these.

Some 2.5 km North to North-East of the mountain Snøhetta, by Dovre in central Norway, I found a pegmatite with haematite lamellae between the feldspar minerals. This pegmatite carries aboundant rutile and several iron-bearing minerals. I analysed a single haematite lamellae, 2 mm thick, and found only slight traces of aluminum in it. The titanium content found in the lamellae may come from rutile. Although the paragenesis is rich in iron, the feldspar does not contain measurable amounts of iron, nor does the haematite contain any aluminium.

It might have been expected that feldspars containing iron should crystallize from a pegmatite magma of a composition as mentioned above. Further we might expect alumina minerals as corundum, sillimanite or others.

Numerous chemical analyses, referred to in the geological litterature, indicate the presence of iron in feldspar. But a close examination very often shows that the iron comes from inclusions or impurities. Potash feldspars with undoubted content of iron are best known from the papers of Lacroix (3). Seto (4) has given the results of several chemical analyses, carried out by him on iron feldspars. Among these is a light orthoclase from Madagascar, containing 2.93 % Fe_2O_3, the highest figure. Calculated as $K Fe Si_3O_8$, this gives 11.2 % of iron orthoclase. A flesh coloured orthoclase from Arendal, Norway, quoted by Seto, is more dubious. I do not feel convinced that this is a real homogeneous mineral. It is possible that this mineral corresponds to the red feldspar dusted with haematite, described by Selmer-Olsen. As to the iron content of plagioclases, Seto gives some values slightly exeeding 0.4 %. But neither here I feel convinced that these results come from homogeneous minerals. In an antiperthitic albite from Seiland, Barth (5, 6) found 0.4 % iron feldspar.

By an unfortunate misprint, Barth says that the feldspar contains ferrous iron and gives the formula for the iron feldspar as $Fe Al_2Si_2O_8$. In a letter to G. T. Faust (7) quoted on page 762 in Fausts paper, Barth, however, states that it is a misprint and that the iron is found as ferric iron, replacing aluminium. This is the only natural interpretation. Faust (op. cit.) arrived at the same conclusion in his work on the system $K_2O—Fe_2O_3—Si O_2$. Faust found that iron orthoclase was formed by crystallization of these components. As to the analogous system $Na_2O—Fe_2O_3—Si O_2$, Bowen, Schairer and Willems (8) did not succed in getting an iron albite. They always got aegirine and quartz. Neither was it possible to obtain iron anorthite synthetically. Homogeneous plagioclases, with iron replacing some of the aluminum, must consequently have been formed under physical and chemical conditions different from those that allowed iron orthoclase to crystallize from supercooled melts.

It is not very probable, however, that the orthoclase from Madagascar crystallized from dry melts. Most likely volatiles and flux were active by the formation of the Madagascar pegmatites. The temperature probably was lower than the solidus temperatures observed by Faust for dry melts.

Anyhow, there seems to be no doubt about the fact that under certain geological conditions minerals of an isomorphic series

$KAl\,Si_3O_8$—$KFe\,Si_3O_8$ may form. It is further reasonable that to a certain degree minerals from the isomorphic composition $Na\,Al\,Si_3O_8$—$Na\,Fe\,Si_3O_8$ may be found.

The ionic radius of Fe^{+++} is 0.67 Å and the ionic radius of Al^{+++} is 0.57 Å. This makes is reasonable that the steric conditions for the formation of $NaFeSi_3O_8$ is more difficult than the formation of $KFe\,Si_3O_8$. The orthoclase cell containing the large $K+$ ion $R = 1.43$ Å is less compact than the albite cell with the small $Na+$ ion $R = 0.96$ Å.

Andersen's hypothesis for the exsolution of haematite from albite by cooling, is not proved by his own experiments. It is correct that the transparent haematite lamellae disappeared by heating the aventurines to 1235° C. By heating these minerals for 45 hours at 1050°, however, opaque lamellae reappeared at the same place as the original haematite lamellae. Andersen interprets these observations in the logical way that thin light coloured ferric glass lamellae are formed at 1230° in the feldspar. At 1050° this glass devitrifizes, forming albite and haematite. Taking a fresh aventurine and heating it for 45 days at 1050°, he finds only a very slight resorbtion of the haematite lamellae. It is beyond doubt that the aventurines had never previously been heated to such a temperature.

Barth (op. cit. 6) has among other examinations also examined the optical conditions of the orthoclases rich in iron from Madagascar. He finds that these minerals have optical constants characteristic for minerals formed by low temperature. Heating of the minerals for a very short time changed the angle of the optical axis from 50° to 25°. The symmetry and colour, however, remained unchanged.

According to these investigations it seems to me that we have no indication for the theory that the feldspars containing iron in solid solution should be typical high temperature minerals.

Laboratory investigations.

The rather frequent parageneses of microcline and iron oxide offers a problem of physico—chemical nature. It seems possible to solve this problem only by experimental investigations. It is, for instance, necessary to know the real solubility of Fe_2O_3 in potash feldspar at different temperatures. This solubility depends, of course, on the concentration of alcali, alumina and iron oxide. Such an investigation, taking all variable factors into account, would be very helpful, but a complete study of the system is at the moment beyond the possibilities of our laboratory. I therefore choose, only to determine the equilibrium concentration of iron in feldspar heated together with equal amounts of iron oxide, and with a mixture of Fe_2O_3 and Al_2O_3. The laboratory investigation was carried out in the manner described below.

Radioactive iron oxide was prepared from radioactive iron, containing Fe^{55} and F^{59}. The total radioactivity was of the order 30 μC per gram. This radioactive iron was delivered once a month from Isotope Division A E R E, Harwell, Didcot, England. I should like to bring them my best thanks for the good service.

The radioactive iron oxide was mixed with a fine crushed feldspar powder. The feldspar powder was prepared from a light pink microcline microperthite from Einerkilen, near Evje. The feldspar appearently was specially poor in iron. The melted feldspar glass was quite colourless. From the fine crushed feldspar powder only the fraction passing sieve no. 325 (Tyler) i. e. 44 μ was used. The feldspar powder thus obtained was mixed with a consentrated solution of iron cloride. To this mixture amonia was added, thus precipitating the iron hydroxide. The amount of iron oxide precipitated was in each case equal to the amount of feldspar. In this way the most effective mixture of iron hydroxide and feldspar was obtained. This mixture was filtered off, washed and dried at 200° C. After cooling the mixture was pressed to tablets, using a pressure of 3000 kg/cm^2. The tablets had a good consistence and could be handled fairly roughly.

The tablets obtained, were placed in furnaces in order to be tempered to equilibrium. Mostly 4 tablets were tempered at various temperatures. It was easily controlled that diffusion equilibrium really had taken place. This was done by removing the tablets from the furnaces at different times. After cooling, the tablets were crushed and heated with aqua regia till all iron oxide was dissolved. The iron content of the feldspar is only to a minor amount affected by this treatment.

The tablets treated in this way showed at the beginning an increasing radioactivity in the feldspar phase. After a certain time, however, the radioactivity reached a maximum and further tempering did not increase the radioactivity of the feldspar to any measurable

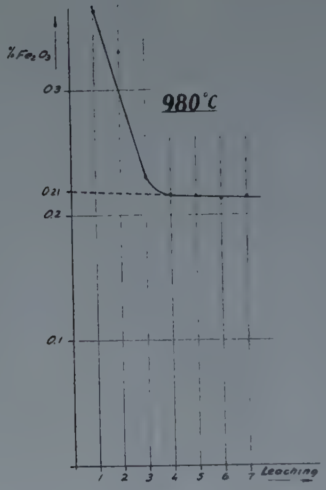

Fig. 1.

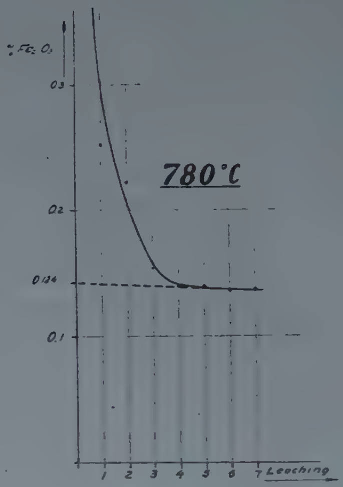

Fig. 2.

amount. This makes it probable that the equilibrium conditions had been reached. This means that the iron in the feldspar had the same percentage of Fe^{55} and Fe^{59} as the iron in the iron oxide. Because of the fine-grained feldspar material, the equilibrium is reached in a fairly short time (i.e.) less than two hours at 980° C, less than 12 hours at 780° C, less than 48 hours at 600° C and less than 168 hours at 480° C.

According to this, the times and temperatures mentioned were chosen for the experiments. The radioactivity of the feldspar residue after leaching with aqua regia, could be recalculated to the content of Fe_2O_3. The measurements were done in the following way:

The tablets of hot feldspar and iron oxide were leached for half an hour with aqua regia. The undissolved silicates were filtered off and the radioactivity of 100 mg was measured. After this, the sample was again leached with aqua regia for half an hour, and the radioactivity of the undissolved part of the sample measured. In this way leaching and measuring were repeated until the radioactivity remained constant. It proved, however, impossible to obtain absolutely constant radioactivity. The radioactivity always decreased a little by continuous treatment with aqua regia. It seems reasonable that this slow decrease in radioactivity is caused by leaching of the feldspar. In order to determine the iron content which has really existed in the

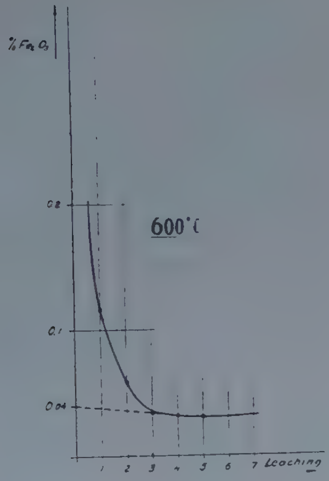

Fig. 3.

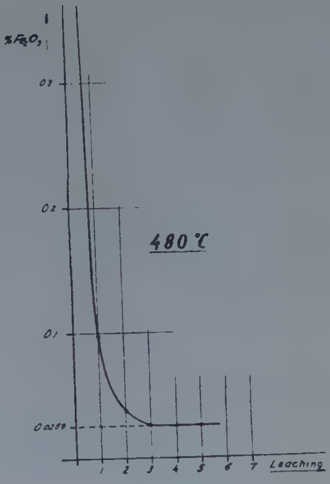

Fig. 4.

feldspar in equilibrium with the iron oxide, we therefore have to extrapolate from the last measurement back to the starting point, i. e. the radioactivity of the feldspar before the treatment by acid. The figures 1, 2, 3, 4 shows the measurements performed. Figure 5 shows a diagram where the temperature is along the X axis and the iron content of the feldspar along the Y axis. I think this iron content represents the amount of iron orthoclase which can be kept in stable solution in the microcline investigated at the corresponding temperature and chemical conditions. The equilibrium may be given by the following equations:

$$\text{I.}\quad 2\text{KAl Si}_3\text{O}_8 + \text{Fe}_2\text{O}_3 \leftrightarrows 2\text{K Fe Si}_3\text{O}_8 + \text{Al}_2\,\text{O}_3$$

$$\text{II.}\quad \frac{a^2(\text{K Al Si}_3\text{O}_8)\cdot a(\text{Fe}_2\text{O}_3)}{a^2(\text{K Fe Si}_3\text{O}_8)\cdot a(\text{Al}_2\text{O}_3)\ (\text{PT})} = \text{K}$$

We must be aware of the fact, that the law of the mass action cannot be used on a heterogeneous system without taking certain reservations. We must assume, that the equilibrium constant represents the equilibrium in a homogeneous phase in or between the grains of the tablets. In the case treated, however, we may use the law of mass action without any special precaution.

The values found in figure 5 represent equilibria. Iron microcline and aluminum microcline are completely isomorphous, and haematite and corundum are also isomorphous. We may hence treat the mixture, when in equilibrium, in the same way as uniphased systems. The amount of iron oxide which enters the feldspar lattice is equal to the amount of alumina which enters the haematite lattice. The determination of the iron oxide content of the microcline phase hence gives the equilibrium constant of the reaction, provided the activity coefficient of iron oxide in feldspars is constant at the concentrations and temperatures in question. Further we may assume that the activity coefficient of alumina in the haematite phase is constant and equal to unity. Basing on these suppositions we may calculate the equilibrium constant.

The first series of experiments were performed with equal amounts (by weight) of microcline and haematite. At a temperature of 980° C we find an

$$\text{“equilibrium constant”} = 1.48 \cdot 10^8.$$

In order to check the supposition mentioned above, some additional experiments were carried out. In these cases the equilibrium concentration of iron oxide in the microcline phase was determined, using a mixture of ⅔ Fe_2O_3 and ⅓ Al_2O_3 instead of pure iron oxide.

Under these conditions the iron oxide contents of the feldspar phases were much lower than in the first cases. At 980° C the iron oxide content was 0.02 %, which gives an

$$\text{“equilibrium constant”} = 0.87 \cdot 10^8.$$

At the lower temperatures the iron oxide content of the feldspar phase was still lower. Actually the radioactivity was so low, that it was impossible to measure it with any accuracy.

If the activity coefficient of iron oxide in the iron microcline phase should be calculated as a function of the temperatures, the corresponding activity coefficients of alumina in haematite must be known.

As far as I know, no statement of the activity coefficient of aluminum oxide in the haematite phase as a function of temperature and concentration is given in the litterature.

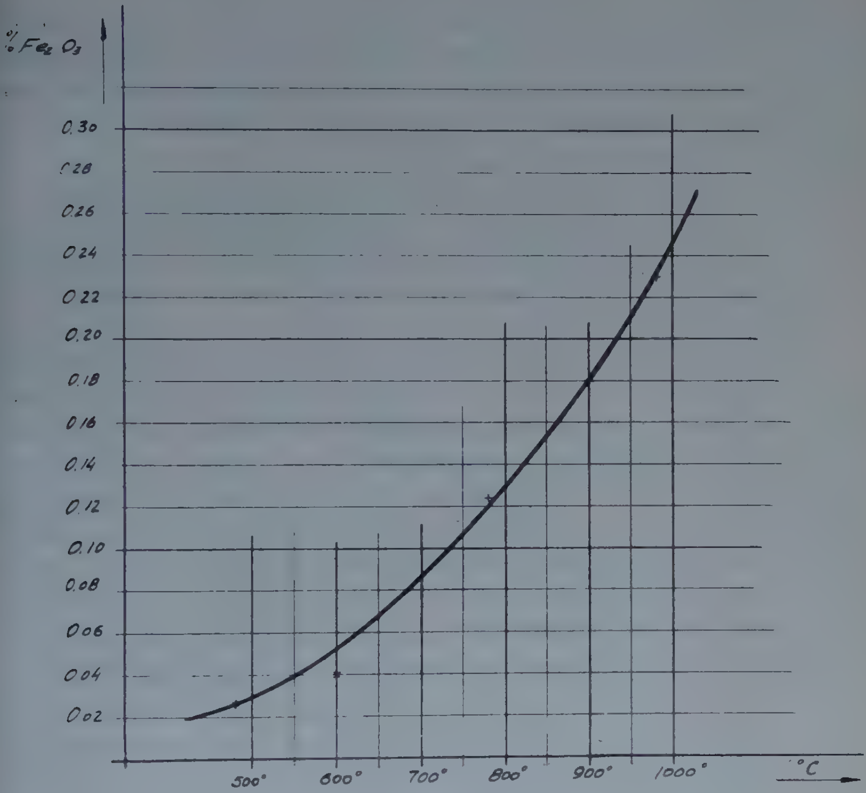

Fig. 5.

The fact, that the two "equilibrium constants" observed at 980° C, i. e. $0.87 \cdot 10^8$ and $1.5 \cdot 10^8$, are nearly the same, although the concentration of aluminum oxide in the haematite phase varied from 0.2 %—33.3 %, indicates that no important differences in the activity coefficient of iron oxide in potash feldspar occurs in the concentration intervall 0.02 %—0.2 %.

We may calculate the "equilibrium constant" at the lower temperatures in the same way. The measurements give at

780° C "equilibrium constant" $= 9.0 \cdot 10^8$
600° C » » $= 2.6 \cdot 10^{10}$
480° C » » $= 1.1 \cdot 10^{11}$.

Supposing the activity coefficient of iron oxide in the feldspar phase to be $= 1$ at this and lower concentrations, we may calculate the amount of iron oxide which will exist in the feldspar phase in equilibrium with a haematite phase consisting of ⅔ Fe_2O_3 and ½ Al_2O_3. The concentrations will be

900° C $= 0.02$ % Fe_2O_3 (measured)
780° C $= 0.0063$ » » (calculated)
600° C $= 0.0011$ » » »
475° C $= 0.0005$ » » »

From the figures above we may conclude; if a feldspar crystallizes with any noticeable amount of iron oxide, the iron oxide activity in the surrounding magma from which the feldspar crystallizes must be extremely higher than the aluminium oxide activity. We assume that pegmatite feldspar crystallizes at a temperature around 600^{c}. The ratio between the iron oxide activity and the aluminum oxide activity must be 2 : 1 if a microcline containing 0.001 % Fe_2O_3 shall crystallize. Feldspar containing so little iron is most probably not found in our pegmatites, and we may therefore assume that the ratio between the iron oxide and the aluminum oxide activity has been higher.

From the amount of iron oxide entering the feldspar phase and the amount of aluminum oxide liberated, we find that at 600° C the ratio between the iron oxide activity and the aluminum activity in the magma bordering to the growing crystal must have been 2500 : 1 if a feldspar with an iron oxide content $= 0.04$ % has crystallized. The ratio between the iron oxide activity and the aluminum activity must increase beyond this limit if a crystal of potash feldspar richer in iron is going to crystallize. According to this we must conclude that the homogeneous feldspars rich in iron crystallized from a surrounding phase where the $Fe_2O_3 : Al_2O_3$ ratio was extremely high. This is the case even when the feldspar only contains some $^1/_{100}$ of a per cent iron oxide.

Most of the pegmatites where potash feldspar is found, contain more aluminum oxide than iron oxide. This is, however, no contradiction to the statement given above. We must assume, that a feldspar crystallizes from a magma in the following way.

At first a tiny seed crystal forms. This seed crystal will contain much more aluminum than iron. In this way nearly all aluminum ions disappear from the immediate surroundings at the seed crystal. Consequently the adjacent magma layer will be enriched in iron relatively to aluminum. If the crystal shall continue to grow, aluminum ions from adjacent parts of the magma must diffuse through this layer.

Such a diffusion is a very slow process, and it will always result in an equilibrium between the iron oxide content and the aluminum oxide content in the magma layer nearest to the crystal surface. It seems probable that this equilibrium generally must be represented by a high Fe_2O_3—Al_2O_3 ratio, as most aluminium ions reaching the crystal surface will precipitate on it, while only very few iron ions will precipitate.

We must concequently assume that if aluminum oxide is added to a feldspar, rich in iron, the feldspar will embody the aluminum ions and expell the iron ions as haematite. This replacement will continue until the feldspar has only so much iron left as corresponds to the equilibrium feldspar : haematite. This equilibrium is according to my opinion represented by figure 5 provided a pressure of one atmosphere and a ratio $Al/Alk = 1$. The influence of pressure of this equilibrium is unknown. We may, however, assume that the equilibrium by increasing pressure may shift against higher iron content of the feldspars by an equal Fe_2O_3/Al_2O_3 ratio in the magma. Ordinary the Fe_2O_3 content probably is of the same order of magnitude as found by one atmosphere.

From the above we may conclude that feldspar containing iron ore minerals e. g. the aventurines are formed from a homogenous feldspar. The exsolution, however, is not caused by a change of temperature, as stated by Olaf Andersen, but by a replacement. I think that feldspar rich in iron at first crystallized from a magma or a solution with an aluminium *deficit*. Under these conditions, a feldspar may crystallize where a part of the aluminum positions of the lattice is occupied by iron ions. After the crystallization has taken place, we may assume that the aluminium : alcali, or the Fe_2O_3 : Al_2O_3, ratio changed in such a way, that the iron substituting aluminum was replaced by aluminum. The iron thus expelled formed the haematite lamellae.

I think that the iron ore content so frequently found in potash feldspars very often is a result of aluminum metasomatism. It was to elucidate this point I prepared the tablets consisting of microcline powder with ⅔ iron oxide and ⅓ aluminum oxide. As previously mentioned these experiments proved the effect of increasing Al_2O_3 activity.

In many cases it is probable that the alcali activity of the rock has decreased after the crystallization. Such decrease in the alcali activity will of course, lead to the same exolution of iron as an addition of aluminum. This conclusion gives an explanation of the deep red colour of, for instance, the tønsbergite syenite. The common opinion among the Norwegian petrologists, seems to be that the red colour of the tønsbergite is caused by oxydation of ferrous iron. This opinion has been hold up by W. C. Brøgger in his courses in petrology by the University of Oslo and later the same opinion has been hold by V. M. Goldschmidt. It seems, however, to be very uncertain that the Fe_2O_3/Fe_2O_3 ratio is any higher in the tønsbergite than in the larvikite. Moreover it is difficult to understand how a rock can obtain a red colour by athmospheric oxydation hundreds of meters below the surface. The explanation given in this paper seems to me, more probable and in accordance to the laboratory observations.

At last I will bring my best thanks to Guri Taraldrud, Chr. Sundre Lauritzen and Øystein Tuntland for the very helpful assistance they have rendered during the experiments. The experimental part of this paper is done in the laboratories of the Norwegian Defence Research Establishment.

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CORUNDUM AT FARSJØ, NES, ROMERIKE

BY

CARL BUGGE

In late autumn 1949 a specimen of a mineral from Årnes at Nes in Romerike was brought to the Geological Survey of Norway (Norges geologiske undersøkelse). The mineral proved to be corundum. The name of the finder is Andreas Martinsen. He had a pocket full of hexagonal tabular to prism-formed crystals. Most of them were about 2 cm in diameter and about 5 mm thick. The dimensions vary such that the largest diameter among the specimens brought are about 4 cm and many were 1.6 to 1.8 cm thick. The colour is brown with yellow shades. The hardness varies somewhat. Glass can be scratched, but some of the tables could be scratched with knife, which may be due to metamorphism into gibbsite, (hydrargillite). Determination of the refraction confirmed our assumption that the mineral was corundum. At my request Mr. Martinsen came back a few days later bringing some pieces of rocks from the locality. The corundum bearing rock proved to be a light mica schist, which could be partly characterized as a strongly pressed micaceous gneiss. The brown tables are embedded in the mica schist. Further the rock consists of a light mica resembling margarite. Some plagioclase is also seen. On November 19, 1949, I took the train to Årnes to examine the occurrence. Årnes is a station on the railway from Oslo to Kongsvinger. The distance from Oslo is 58 km. The locality where the corundum is found is situated at the south end of Farsjø, which is about 7 km southeast of Årnes railway station. Unfortunately, winter had come, so it could only be a preliminary orientation.

Mr. Martinsen took me to the locality which extends along the western side of the river Sagstuåen near the outlet of Farsjø. On the east side, the place Sagstuen is situated. The situation is seen from Figs. 1 and 2.

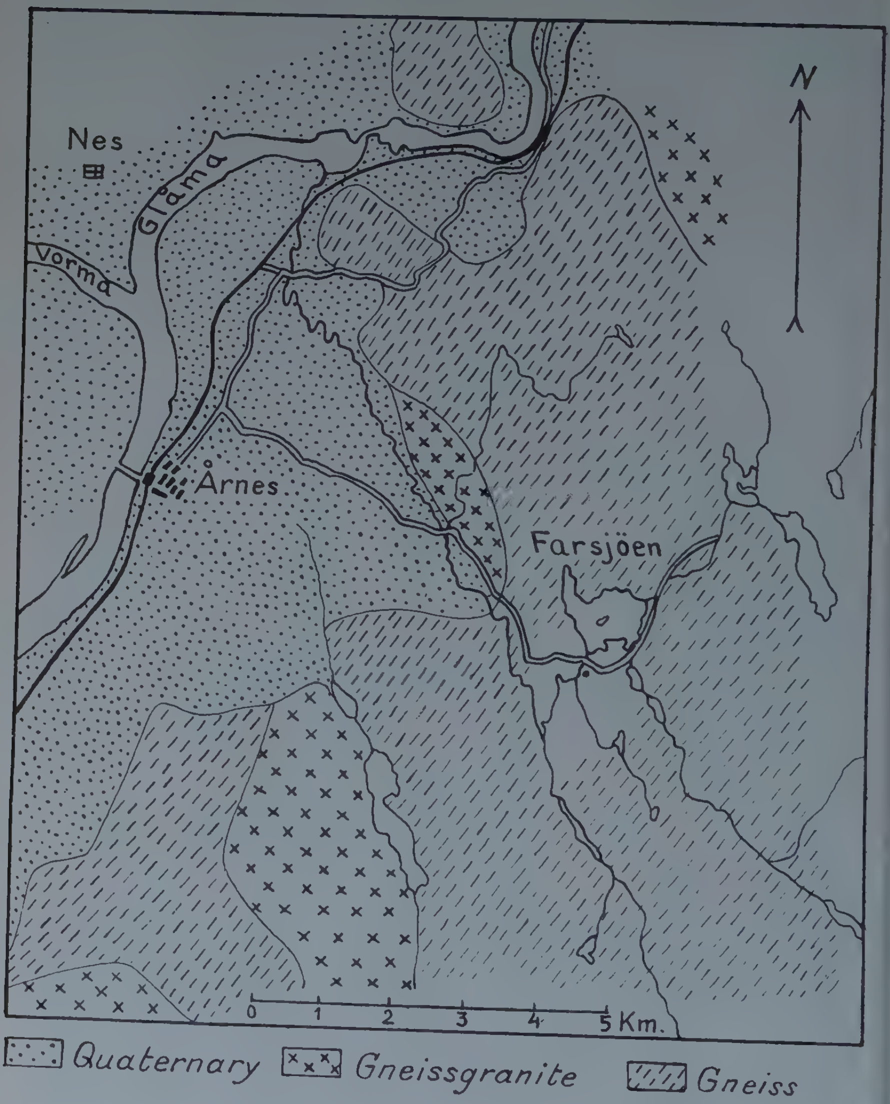

Fig. 1.

People living in the vicinity had for a long time known of these brown tables, they thought it strange that they were always hexagonal, and that was the reason why Mr. Martinsen communicated with the Geological Survey of Norway.

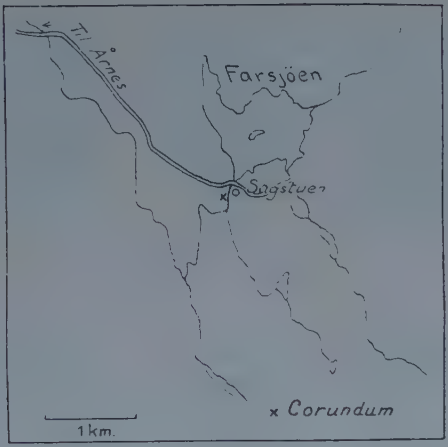

Fig. 2.

Reference is made to the geological quadrangle, Nannestad. Farsjø is situated on the eastern part of this map. The eastern part of this quadrangle was mapped geologically in 1884 by T. Ch. Thomassen. Fig. 1 shows a copy after Thomassen's geological map. According to his description, several kinds of gneiss occur, thus mica gneiss, hornblende gneiss and garnet gneiss. The granite is mentioned as striped granite (stripet granitt).

The corundum occurs in a mica schist along the westside of the river, partly also in the river-bed itself. The strike varies somewhat, chiefly N 20° W, the dip about 34° S. The zone containing corundum begins about 50 meters south of the road and can be followed about 200 meters along the river. The breadth of the zone might perhaps be 10—15 meters. This will be easier determinable in summertime. Mr. Martinsen said that he had found corundum some hundred meters further south.

The mica schist contains light mica and a basic plagioclase. In thin sections leucoxene is also seen.

Mica occurs in large quantitities as thin, light, shining laths. As margarite appears at so many corundum occurrences, it is of interest that the mica at Farsjø resembles margarite. Determination of the refractive index indicates, however, that the mica is nearer to muscovite (see page 82). This question, therefore, must be looked further into when more material has been collected, so that a chemical analysis can be carried out. The mica, in which corundum is found, borders to the west on a pressed gabbro rock. This consists of basic plagioclase and hornblende. Likewise leucoxene is seen. The hornblende shows axial plane 010, opt.neg.

$\gamma =$ dark blueish green.
$\beta =$ dark green.
$\alpha =$ light yellow.
$c : \gamma = 17°$.

Regarding the plagioclase reference is made to pag. 82.

Of chemical analysis so far I have had carried out determination only of Al_2O_3 in the corundum and in the mica schist. The analyses have been carried out by Civil Engineer Brynjolf Bruun of Statens Råstofflaboratorium (The State Raw Material Laboratory),

	Corundum	Mica Schist containing Corundum
Al_2O_3	93.15 %	28.33 %

The analyses of the corundum is indicative of a hydration having taken place. This also appears from a thin section, showing under the microscope that the corundum is traversed by numerous veins, presumably consisting of gibbsite and diaspore. In between the hydrated veins small parties of primary corundum are seen in polarized light, with rather lively interference colours, because the thin section is comparatively thick. In another section all corundum is evidently hydrated.

The corundum crystals were examined by dr. Jens A. W. Bugge of the Geological Institute, The Technical University of Norway. He makes the following statement:

The forms appearing on the corundum crystals are

c $\{0001\}$ pinacoid
a $\{11\bar{2}0\}$ hexagonal prism of the 2nd order
r $\{10\bar{1}1\}$ rhombohedrons of the 1st order
n $\{22\bar{4}3\}$ hexagonal dipyramid of the 2nd order.

Indices for the planes were determined by the following angles corresponding with those given by Hintze in "Handbuch der Mineralogie": cr — 57° 34′, rr — 93° 56′, cn — 61° 11′, nn — 51° 58′.

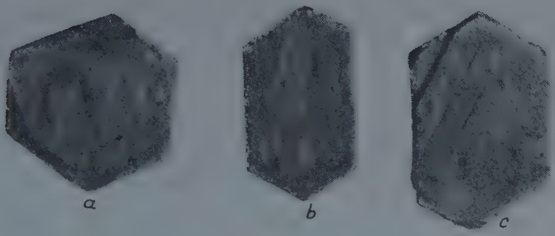

Fig. 3.

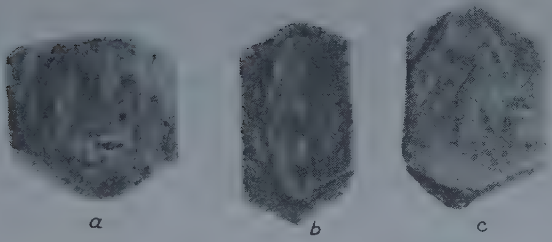

Fig. 4.

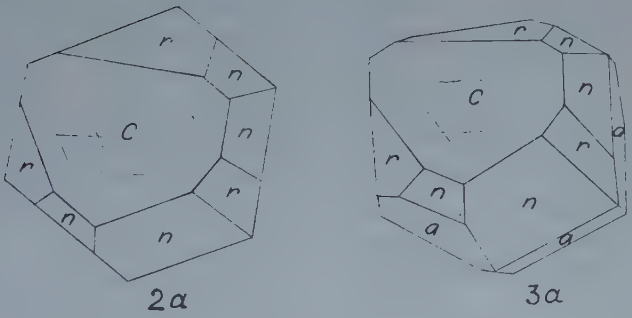

Fig. 5.

As several of the planes are rather uneven an inaccuracy of ± 30′ is found. Figs. 3 and 4 show characteristic corundum crystals. In fig. 3 they are photographed vertically on 0001, in fig. 4 at an oblique angle so that the prism planes are seen. Fig. 5 shows a drawing of figs. 3 a and 4 a. As will be seen, planes of the same form are of rather varying sizes. The lower pyramid planes and two of the upper ones are not developed at all.

Figs. b and c are tabular in habit. Fig. b has only developed the forms $\{0001\}$ and $\{11\bar{2}0\}$, while fig. c also has developed the rhombohedron $\{10\bar{1}1\}$. It is seen as small pyramids on the basis planes. On the lower basis plane the triangles are lying with the points orientated contrawise.

All crystals show a fine streaking and a lamellar twinformation parallel to $10\bar{1}1$. The white veins on the crystal planes have arisen through the metamorphism of the corundum.

Jens Bugge has at the same time examined the light mica which occurs together with corundum and the plagioclase in the pressed gabbro rock. With regard to the mica he states:

Light mica was determined by refraction index on 001 : $\gamma'_{Na} = 1.600$. Axial angle was determined with a Federow-table to $2V = -40°$ and the angle between the acute bisectrix α and the normal on $001 = 2°$. According to Winchell this corresponds to a mica of the muscovite series:

47 pct. muscovite
33 pct. phengite
20 pct. Fe^{III}-phengite.

Together with the light mica some chlorite appears. It shows $\beta_{Na} = 1.607$ and $2V = 0°$, very low birefringence. According to Winchells tables it is delessite ɔ: penninite, rich in iron. Pleochroism

$\gamma = \beta =$ green
$\alpha =$ pale yellow.

The plagioclase in the pressed gabbro rock was determined by the index of refraction on the cleavage plane: $\alpha'_{Na} = 1.570$, which corresponds to $Ab_{20}\,An_{80}$.

As regards previous findings of corundum in Norway it is stated that J. H. L. Vogt (1910) mentions corundum in titanoferous magnetite which occurs in a pressed gabbroic rock at Rausand in North western Norway. Small granules of corundum have been traced in thin sections. J. Schetelig (1916) and Barth (1927) have described corundum as crystals in pegmatite on Seiland. The mineral was first found by A. Hoel. N. H. Kolderup (1936) has described corundum in anorthosite gabbro in the Bergen field.

In the Oslo region traces of corundum are found in some contactmarble, for instance Gjellebekk in Lier. This type of occurrence will be the subject of a future investigation.

As regard occurrences of corundum in other countries it may be said that the mineral is found both as metamorphosed mineral and in magmatic rocks and it is also found alluvially.

As regards corundum of magmatic genesis it is a peculiar fact that the corundum is not exclusively found in rocks high in alumina but also in connection with rocks poor in alumina and at the same time low in silica (peridotite).

In Ontario corundum occurs in syenites, partly nepheline syenites. In U. S. A. corundum and emery occur in many places. In basic rocks (peridotite, gabbro, norite) corundum and emery are found at many places along the Appalachian region from Alabama to Massachusetts.

In Transvaal large occurrences of corundum and emery are found in coarse-grained diorite and in pegmatite. There are also occurrences of corundum on Madagascar and in India.

The largest known occurrences of emery are on the island Naxos and other islands in the Greek Archipelago and in some places in Asia Minor. In these places emery occurs in metamorphosed limestone.

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GRANITIZATION AND BASIFICATION BY DIFFUSION[1]

BY

E. C. T. Chao

Introduction.

In many parts of the world it has been shown that granite and allied rocks have formed by replacement of pre-existing rocks. Indeed, hardly any geologist today will doubt the importance of metasomatic processes in petrogenesis. However, the physical nature of the active agents and the mechanism of the process are still much debated.

It has been proposed that the transfer of the chemical material was effected for example as mineral molecules or as oxides by a magma, a pore liquid, a gas, or by a hydrothermal solution. More recently various authors have maintained that free atoms, loosened from the crystalline lattice, are responsible for the transfer.

In the present paper eight examples of granitization and basification taken from the literature, will be discussed. It will be shown that the chemical data are susceptible to reinterpretation as based on the importance of diffusion in the transfer of chemical material. This means that material has been transferred in the form of individually moving atoms, molecules or ions, and not in the form of flowing liquid.

It has recently been emphasized by Barth that if rock alterations take place without change of volume, it can be assumed that little net loss or gain of oxygen took place. This assumption is reasonable because about or over 90 per cent of the rock-forming mineral or rock volume is occupied by oxygen (Barth, 1948 a, Reynolds 1949, p. 247). Therefore discussion of gain and loss of material in rock alteration is greatly facilitated by Barth's concept of standard rock cell (Barth 1948 b) which contains 160 oxygen ions. By listing the cations associated with the unit rock cell, we arrived at the rock formula. By comparing the rock formula of the altered with that of the unaltered parent rock and with that of the associated granite, we obtain the gain and loss of the altered rocks and of the granite in terms of cations.

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[1] Condensed from doctorate thesis at the university of Chicago 1948, subsequently revised.

The gains and losses are comprehensively illustrated by the diagrams, Fig. 1 to 7. With reference to Fig. 1, the diagramms are explained as follows: The rock series from shale to granite consists in this case of 9 analyzed members, they are arranged from right to left in order of increasing granitization. The cation contents of the respective standard cells are calculated.

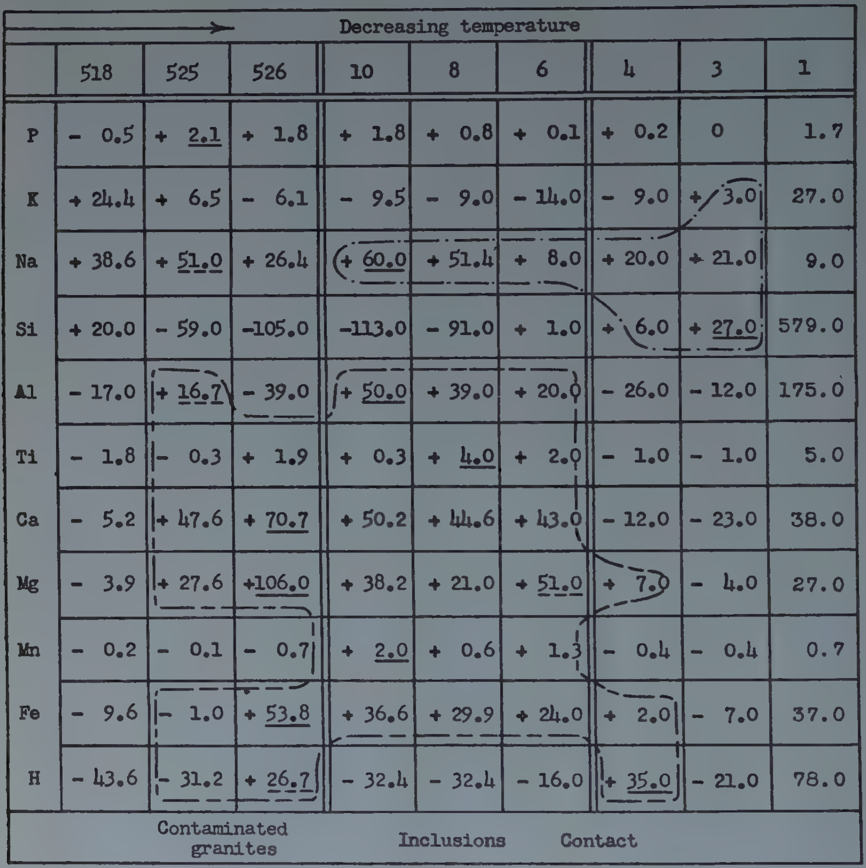
The results of these calculations are here given explicitely for the unaltered shale (1) only. The contents of all other standard cells are compared with that of the unaltered cell and set out in terms of differences. Thus rock No. 3 (shale near the contact) is shown by the diagram to have gained for example 3 K-ions but lost 12 Al-ions, etc., as compared to the composition of the standard cell of the unaltered shale.

Thus the gain and loss diagrams illustrate the variations of the cation content from the unaltered parent rock on the right to the granite on the left through altered rocks of the transitional zone in between as found in nature. The socalled granitization fronts are indicated by dash and dot lines, and the basification fronts by long and short dash lines. The maximum values, corresponding to petrochemical culminations, are underlined. A second maximum is underlined by a dash line.

A. Examples of Inclusions in Granitic Rocks:

1) Sedimentary inclusions in the Boulder Batholith (Grout, 1937, pp. 1559—1563; Reynolds, 1946, pp. 402—403):

No. 518 represents the chemical composition of the prevailing type of Boulder Batholith, a hornblende granite. No. 525 is the contact facies of the granite mass, and No. 526 is a contact facies of granite which is the type that surrounds the inclusions. Nos. 10, 8 and 6 are dark inclusions 300 yards, 100 yards and six inches from the contact. No. 4 is the composition of hornfels breccia at the contact of batolith. No. 3 is Cretaceous shale near the contact. No. 1 is the Cretaceous shale 100 yards outside of the batolith. The gain and loss diagram (Figure 1) shows the trend of chemical changes rather



Decreasing temperature →									
	518	525	526	10	8	6	4	3	1
P	- 0.5	+ 2.1	+ 1.8	+ 1.8	+ 0.8	+ 0.1	+ 0.2	0	1.7
K	+ 24.4	+ 6.5	- 6.1	- 9.5	- 9.0	- 14.0	- 9.0	+ 3.0	27.0
Na	+ 38.6	+ 51.0	+ 26.4	+ 60.0	+ 51.4	+ 8.0	+ 20.0	+ 21.0	9.0
Si	+ 20.0	- 59.0	-105.0	-113.0	- 91.0	+ 1.0	+ 6.0	+ 27.0	579.0
Al	- 17.0	+ 16.7	- 39.0	+ 50.0	+ 39.0	+ 20.0	- 26.0	- 12.0	175.0
Ti	- 1.8	- 0.3	+ 1.9	+ 0.3	+ 4.0	+ 2.0	- 1.0	- 1.0	5.0
Ca	- 5.2	+ 47.6	+ 70.7	+ 50.2	+ 44.6	+ 43.0	- 12.0	- 23.0	38.0
Mg	- 3.9	+ 27.6	+106.0	+ 38.2	+ 21.0	+ 51.0	+ 7.0	- 4.0	27.0
Mn	- 0.2	- 0.1	- 0.7	+ 2.0	+ 0.6	+ 1.3	- 0.4	- 0.4	0.7
Fe	- 9.6	- 1.0	+ 53.8	+ 36.6	+ 29.9	+ 24.0	+ 2.0	- 7.0	37.0
H	- 43.6	- 31.2	+ 26.7	- 32.4	- 32.4	- 16.0	+ 35.0	- 21.0	78.0
		Contaminated granites			Inclusions		Contact		

Fig. 1.

clearly: No. 4 which is closer to granite than No. 3 gained Fe, Mg and H, whereas No. 3 lost Fe, Mg and H but gained K and more Na and Si. By comparing No. 3 with No. 518, the prevailing granite, it is clear that the trend of the change in No. 3 is toward the granite, whereas the change of No. 4 is toward the contaminated granites. The migration is, therefore, Na and Si out of granite in exchange for Mg and Fe from the Cretaceous shale-hornfels.

The trend of change of the inclusions is that the farther inside the granite the more inclusions gain in Na, Al, Ca and Fe, and lose in Si and H. Basification of granite near the contact is also evident. The trend is quite similar to that of the inclusions.

	G	A	B	C
K	53	- 23	- 27	- 16
Na	69	+ 6	- 2	+ 25
Si	618	- 18	- 20	- 27
Al	163	- 2	- 3	+ 11
Ca	14	+ 8	+ 5	+ 6
Mg	16	+ 9	+ 4	+ 13
Fe	20	+ 22	+ 32	+ 8

Contaminated granites

a.

→ Dec. temp.

A	a	a_1
- 46	+ 4	76
+ 39	+ 13	36
+ 143	- 18	457
- 167	+ 51	328
+ 14	- 3	8
+ 11	- 7	14
- 37	- 28	79

Contact

b.

→ Decreasing temperature

B	β_3	β_2	β_1	b	b_1
+ 5	+ 51	+ 38	+ 10	+ 12	21
+ 34	+ 8	+ 50	+ 53	+ 1	33
+ 124	+ 84	+ 62	- 9	+ 30	474
- 106	- 104	- 78	+ 37	- 5	266
- 26	0	- 15	- 34	- 18	45
+ 15	+ 49	+ 52	+ 24	+ 21	5
- 65	- 58	- 58	- 38	- 40	117

Contact

c.

→ Decreasing temperature

C	γ_1	c	c'	c_1
+ 19	+ 65	+ 25	+ 7	18
+ 68	+ 13	+ 3	+ 7	26
+ 61	+ 23	- 58	- 78	530
- 90	- 81	+ 10	+ 17	264
- 12	+ 8	+ 66	+ 88	32
+ 22	+ 51	+ 15	+ 15	7
- 28	- 15	+ 4	+ 13	56

Contact

d.

Fig. 2.

The mineral mode of No. 6 is: 6 per cent quartz, 40 per cent labradorite, 10 per cent biotite, 35 per cent amphibole, and 5 per cent ore minerals. It has on the one hand a more basic feldspar and a larger amount of labradorite and amphibole than the less altered hornfels, on the other hand, less labradorite and more amphibole than the inclusion 100 yards inside the granite. This assemblage is typical of amphibolite facies. The evidence is therefore in favour of the hypothesis that the change of rock composition and the transfer of particles are governed by the development of the stable minerals.

2) Sedimentary inclusions in the Flamanville Granite (Leclere, 1906, pp. 7—11; Reynolds, 1946, pp. 393—397):

The Flamanville granite (G) of Normandy, France cuts obliquely across three horizons of the Devonian sediments composed of fissile shale (a_1), graywacke (b_1), and calcareous shale (c_1). These sediments were altered into metamorphic shale (a), hornfels (b), and calcareous shale (c) and c′ a schistose type of calcareous shale at the contact with the granite. Extending into the granite along the strike of these beds are contaminated granites (A, B, C) and undisturbed relic feldspathized inclusions (β_3), the average inclusion (β_2), and schistose inclusion (β_1) of the graywacke, and a large relic inclusion of the compacted calcareous shale (γ_1).

The gain and loss diagrams (figures 2 a and 2 b) show that in the case of the fissile shale a_1, the Ca, Mg, Fe and Si lost by the altered shale (a) were gained by the contaminated granite A, whereas the loss of K and Al from A was gained by a.

Figure 2 c shows the alteration of b effected by loss of Ca, and Fe, and gain of K and Si, a trend towards granitization as marked by the granitizing front. Similar and progressive changes effected the inclusions β_1, β_2 and β_3. On the other hand the contaminated granite B when compared with G (figure 2 a) indicates loss of K and Si, and gain of Ca and Fe. An exchange of these ions is reasonably clear.

Figure 2 d shows that c and c′ are notably desilicated and basified (marked by the basifying front). The chemical changes of the inclusion γ_1 are similar to those of β_2 and β_3, thus indicating of convergence towards the development of a stable mineral assemblage of originally different sediments. The contaminated granite C again shows complementary changes, i. e. loss of K and Si, and gain of Ca, Mg and Fe.

It is noteworthy that all the altered rocks — sediments and granite —gained Na and Mg. Therefore the chemical changes are not a simple complementary nature, but involve the migration of materials from more distant sources. The explantion is difficult and still obscure; magmatic contamination or assimilation presents no solution.

It should be noticed also that various elements culminate at various places in different types of rocks, and that the culminations of elements do not lie in the most altered rocks (such as the culmination of Al and Ca in c′ instead of c). The ions migrate in various directions; there is an all over addition of Mg and Na. We are forced to conclude, therefore that the operating process was highly selective in the sense of diffusion and differential metasomatism.

B. Examples of Granitized Contacts:

3) The Jurassic sandstone and the granite contact at Dunan, Isle of Skye (Day, 1931, pp. 58—59; Reynolds, 1946, p. 410):

The Tertiary granophyre of Dunan (S_1) with a small amount of hornblende and a distinct granophyric texture altered the Jurassic sandstone Sx. The contact is gradational. The unaltered sandstone

→ Decreasing temperature

	S$_1$	S$_3$	S$_9$	S$_4$	S$_6$	S$_7$	S$_8$	S$_x$
C	+ 1.4	+ 2.0	+ 5.9	− 0.2	+ 0.8	− 0.2	0	0.6
P	0	− 0.3	− 0.3	− 0.3	+ 0.1	+ 0.2	− 0.3	0.3
K	+ 25.6	+ 18.6	+ 23.7	+ 15.4	+ 16.4	+ 14.7	− 0.2	28.0
Na	+ 38.0	+ 33.0	+ 39.5	+ 36.8	+ 33.2	+ 40.6	+ 24.4	27.6
Si	− 88.5	− 68.5	− 107.0	− 83.0	− 84.2	− 87.0	− 24.0	732.0
Al	+ 79.8	+ 47.9	+ 96.3	+ 65.3	+ 64.1	+ 63.4	+ 23.0	58.2
Ti	+ 1.4	+ 1.9	+ 1.7	+ 2.0	+ 2.0	+ 2.3	+ 0.9	tr
Ca	+ 4.7	+ 2.5	+ 2.0	+ 3.4	+ 1.3	+ 1.8	− 1.0	3.9
Mg	+ 1.8	+ 3.6	+ 2.7	+ 0.6	+ 0.6	+ 9.2	+ 2.9	tr
Mn	+ 0.5	+ 0.3	+ 0.4	+ 0.3	+ 0.4	+ 0.5	0	tr
Fe	+ 16.0	+ 17.5	+ 13.9	+ 14.6	+ 22.7	+ 11.9	− 2.7	3.8
H	− 7.2	+ 13.9	+ 2.5	+ 36.1	+ 34.7	+ 42.8	+ 4.2	18.8
		Contaminated granites		Contact				

Fig. 3.

S$_x$ has 88.03 per cent of silica, 5.9 per cent of alumina and 4.2 per cent of total alkalies.

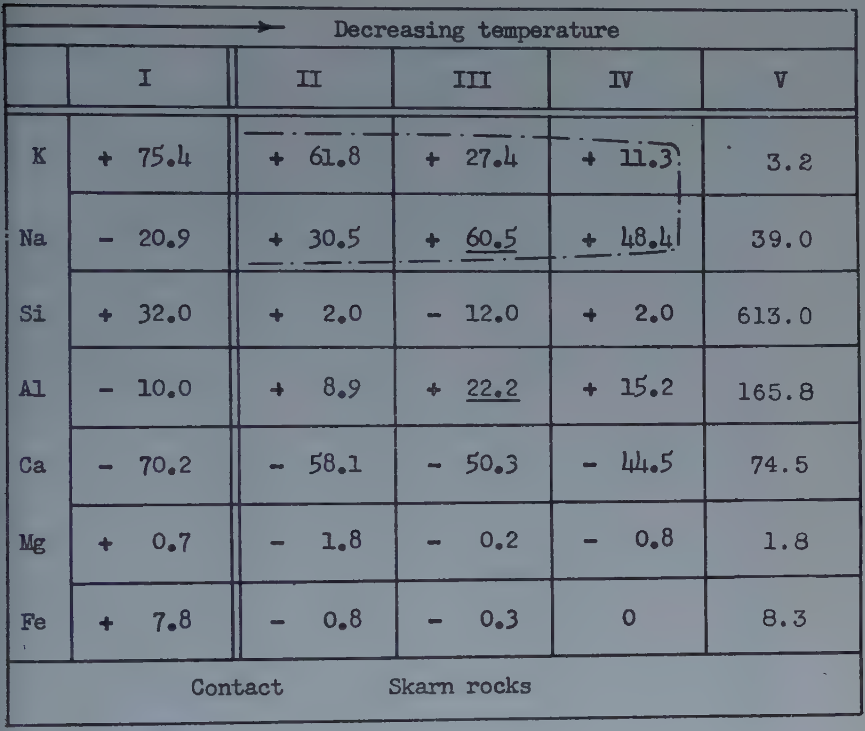
The gain and loss diagram figure 3, shows that all the altered sandstones S$_8$, S$_7$ and S$_6$ which are 100, 10 and 5 feet from contact are desilicated and gained Al, K, and Na as described by the granitizing front. They also gained Fe and H. The petrochemical culminations of Na, Mg, and H in S$_7$, Fe in S$_6$, and Al in S$_9$ together with the second maxima of Mg, Fe and H indicate that the migration of these ions was both from the granophyre and from the sediments. Any such migration evidently is against the concentration gradient.

→ Decreasing temperature					
	7	6	5	4	3
P	- 6.0	- 6.0	0	+ 9.0	6.0
K	+ 31.0	+ 21.0	+ 24.0	- 19.0	20.0
Na	+ 23.0	+ 12.0	- 8.0	- 37.0	49.0
Si	+ 130.0	+ 52.0	+ 13.0	- 70.0	500.0
Al	- 26.0	- 16.0	- 37.0	- 31.0	159.0
Ti	- 15.0	- 15.0	+ 23.0	+ 1.0	16.0
Ca	- 74.0	- 46.0	- 33.0	+ 6.0	84.0
Mg	- 49.0	- 37.0	+ 15.0	+ 1.0	51.0
Mn	- 1.0	+ 1.0	+ 2.0	+ 4.0	1.0
Fe	- 66.0	- 4.0	+ 4.0	+ 136.0	90.0
H	- 20.0	+ 25.0	- 19.0	+ 67.0	92.0
	Granophyre		Epidolerites		Dolerite

Fig. 4.

4) The granophyre and the Breven Dolerite Dike (Krokström, 1932, pp. 289—299, 302—305; Reynolds, 1946, p. 417):

The Breven Dolorite Dike extends east-west for 30 km from Lake Rävsjön to Lake Storsjön in Sweden and has a width of 0.3 to 1 km. The granophyre (7) is in the central portion of the dike, flanked by epidolerite (nos. 6, 5 and 4) on both sides. These altered



→ Decreasing temperature					
	I	II	III	IV	V
K	+ 75.4	+ 61.8	+ 27.4	+ 11.3	3.2
Na	- 20.9	+ 30.5	+ 60.5	+ 48.4	39.0
Si	+ 32.0	+ 2.0	- 12.0	+ 2.0	613.0
Al	- 10.0	+ 8.9	+ 22.2	+ 15.2	165.8
Ca	- 70.2	- 58.1	- 50.3	- 44.5	74.5
Mg	+ 0.7	- 1.8	- 0.2	- 0.8	1.8
Fe	+ 7.8	- 0.8	- 0.3	0	8.3
	Contact		Skarn rocks		

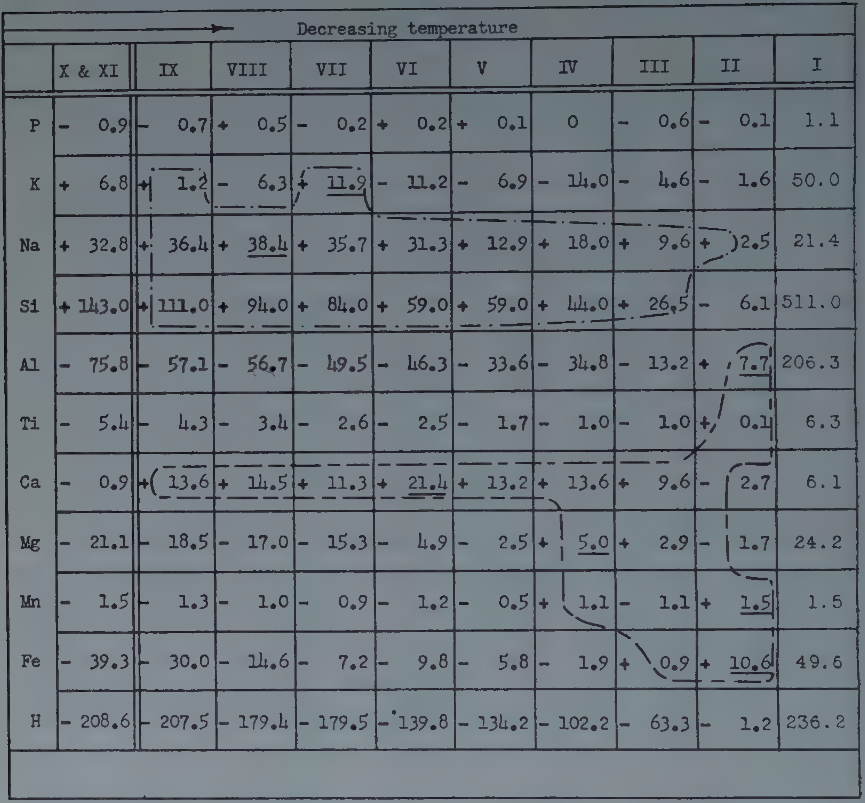
Fig. 5.

epidolerites grade away from the granophyre into olivine free dolerite (3) (see Krokström, 1932, p. 290, fig. 25, and p. 299, fig. 26).

The fresh dolorite is of a speckled black and white color, coarse-grained with large light-colored feldspar-laths. The epidolerite is chemically as well as mineralogically different from the dolerite. The anorthite percentage of the plagioclase decreases gradually from the high values 54 to 62 per cent of the dolerite to 25 to 30 per cent of the epidolerite. Simultaneously the epidolerite becomes enriched in potash feldspar.

The granophyre is red with sporadic green spots of epidote. Phenocrysts of quartz are prominent. The potash feldspar and quartz are partly independent and partly micrographically intergrown.

The first impression is that the dolerite has been retrogressively metamorphosed, caused by intrusion of the granophyre and that the intermediate rock (6) and the acid epidolerite (5) are granitizied.



Decreasing temperature										
	X & XI	IX	VIII	VII	VI	V	IV	III	II	I
P	- 0.9	- 0.7	+ 0.5	- 0.2	+ 0.2	+ 0.1	0	- 0.6	- 0.1	1.1
K	+ 6.8	+ 1.2	- 6.3	+ 11.9	- 11.2	- 6.9	- 14.0	- 4.6	- 1.6	50.0
Na	+ 32.8	+ 36.4	+ 38.4	+ 35.7	+ 31.3	+ 12.9	+ 18.0	+ 9.6	+ 2.5	21.4
Si	+ 143.0	+ 111.0	+ 94.0	+ 84.0	+ 59.0	+ 59.0	+ 44.0	+ 26.5	- 6.1	511.0
Al	- 75.8	- 57.1	- 56.7	- 49.5	- 46.3	- 33.6	- 34.8	- 13.2	+ 7.7	206.3
Ti	- 5.4	- 4.3	- 3.4	- 2.6	- 2.5	- 1.7	- 1.0	- 1.0	+ 0.1	6.3
Ca	- 0.9	+ 13.6	+ 14.5	+ 11.3	+ 21.4	+ 13.2	+ 13.6	+ 9.6	- 2.7	6.1
Mg	- 21.1	- 18.5	- 17.0	- 15.3	- 4.9	- 2.5	+ 5.0	+ 2.9	- 1.7	24.2
Mn	- 1.5	- 1.3	- 1.0	- 0.9	- 1.2	- 0.5	+ 1.1	- 1.1	+ 1.5	1.5
Fe	- 39.3	- 30.0	- 14.6	- 7.2	- 9.8	- 5.8	- 1.9	+ 0.9	+ 10.6	49.6
H	- 208.6	- 207.5	- 179.4	- 179.5	- 139.8	- 134.2	- 102.2	- 63.3	- 1.2	236.2

Fig. 6.

This picture of granitization is not complete, however. Figure 4 indicates that the basic epidolerite (4) has lost K, Na, Si and Al. and gained all other ions, especially Fe with consequent development of amphibole and biotite in (4) and (5) (amphibolitization). Thus K, Na and Si migrate towards the granophyre, the basic ions the other way, causing granitization of (6), and probably influencing the formation of the granophyre itself.

No assimilation of dolerite by granophyre took place, there is no field indication of any solution accompanying the granophyre. The compositional changes of the epidolerites are, therefore, most likely due to diffusion, no matter how slow it might have been, in a fairly dry state. The original zoned plagioclase in the dolerite was in this case homogenized.

→ Decreasing temperature									
	A	B	8	7	6	5	4	3	2
K	- 10.2	- 7.7	- 2.2	- 29.1	- 9.5	+ 14.1	- 24.3	- 11.4	51.9
Na	+ 56.2	+ 43.9	+ 26.8	+ 50.0	+ 24.7	+ 11.3	+ 5.9	+ 7.7	10.5
Si	- 136.0	- 106.0	- 39.0	- 61.0	- 47.0	- 66.0	+ 46.0	+ 11.0	691.0
Al	+ 101.4	+ 97.7	+ 38.8	+ 41.7	+ 39.9	+ 64.0	- 25.6	+ 4.7	76.3
Ti	+ 5.3	+ 2.2	+ 1.3	+ 0.6	+ 3.7	+ 2.6	- 0.5	+ 0.9	1.2
Ca	+ 47.9	+ 31.3	+ 1.1	+ 0.2	+ 0.4	+ 2.4	+ 3.1	+ 0.5	0.4
Mg	+ 22.1	+ 13.0	+ 13.4	- 0.2	+ 12.8	+ 13.0	- 0.5	- 0.1	0.5
Fe	+ 15.2	+ 2.0	- 3.4	+ 35.7	+ 3.1	- 7.2	- 17.0	- 12.1	28.0
H	- 4.6	- 16.5	- 9.3	- 15.1	- 6.3	+ 21.5	- 49.0	- 24.0	63.3
	Gneisses		Granulites			Schistose sparagmites			

Fig. 7.

5) Contact of pegmatite and limestone of Mansjö Mountain, Sweden (Eckermann, 1922, p. 326):

The skarn rocks developed at the contact of a pegmatite inside the limestone formation at Stora Kalkbrottet of the Mansjö Mountain, Sweden. The pegmatite is made up of perthitic microcline, plagioclase of An 25 per cent, quartz, plus accessory biotite and zircon. The composition of a pegmatite is rather difficult to determine by chemical analysis, and the composition of the closely related granite gneiss is given instead (I). II—V (diagram figure 5) represent skarn rocks collected at one quarter, one-half, one, and two meters from the contact.

Chemical exchange took place within these two meters of rock. The gain and loss variation diagram, figure 5, indicates progressive gains of K by the skarn rocks approaching the contact, and gain of

Na and Al with their culmination at a distance of one-half meter from the contact. Ca and, possibly, small amounts of Mg were lost by the skarn (partly accounting for the high An per cent of the plagioclase of the pegmatite). The exchange of material and the petrochemical culminations of Na and Al seem to be best explained by fractional diffusion in two directions. This phenomenon is difficult if not impossible to explain by soaking in a mobile pegmatitic liquid.

C. Examples of Granitization on a Regional Scale.

6) Example of granitization of the Stavanger region (Goldschmidt, 1920, p. 110; MacGregor and Wilson, 1939, p. 196; Reynolds, 1946, p. 405):

The classical work of Goldschmidt gives us a series of no less than ten analyses including granite (X & XI), gneiss (IX, dark layer), augen gneiss (VIII), mica-rich augen gneiss (VII), porphyritic albite schist (VI, average of 6 samples), quartz-muscovite-biotite-garnet-mica schist (V, average of 4), quartz-muscovite-biotite-garnet schist (IV, average of 6), quartz-muscovite-biotite phyllite (III), quartz-muscovite-chlorite-garnet phyllite (II, average of 8) and quartz-muscovite-chlorite phyllite (I, average of 18) farthest away from the granite.

The gain and loss variation diagram, figure 6, of these regionally metamorphosed Cambro-silurian sediments clearly shows the fixed granitizing front and the fixed basifying front. The former is indicated by the progressive gain of Na, and Si by rocks closer to the granite and the latter, the gain of Ca, Mg, Mn, and Fe. Such radical change of chemical composition of the basified II, III and IV and the granitized V, VI, VII, VIII and IX is regional in scale. From the overlapping of the two fronts, the complementary nature of the migration and exchange of mineral matter is clear. This fact is further shown by the independent petro-chemical culmination of different ions at various distances from any reference plane parallel to the contact.

It should not be overlooked that granitization in this case was also accompanied by the loss of Al and dehydration. In other words, there is no evidence of a hydrothermal phase connected with the granite.

7) The sparagmite rocks of southern Norway (Barth, 1938, pp. 58 and 63):

The composition of the Eocambrian sparagmites of southwestern Norway are mineralogically the same as the rocks termed "arkose" in the United States. They consist almost exclusively of fragments of quartz and feldspar and are frequently conglomeratic. The uniform composition throughout the whole formation of the sparagmite in southern Norway is well known to Norwegian geologists. These sparagmites (2 to 5) are progressively metamorphosed (in space) into "granulites" or flagstones (6 to 8) which grade into the basal gneisses (B and A) from southeast to northwest during the Caledonian orogenesis.

The chemical changes of the altered sparagmatite are not distinct probably because the original composition of the sparagmite is close to that of a granite. Figure 7, shows that in general, the sparagmites and granulites show desilication and an increase of Na, and Al. The change is towards becoming more like the basal gneisses and the culmination of Na, K and Al is correlated to albitization, the recrystallization of potash feldspar and the increase of muscovite (Barth, 1938, p. 60).

Other examples of granitization on a regional scale such as that described by Quirke and Collins (1930), MacGregor and Wilson (1939) and Reynolds (1946) are available and in general serve as field evidence in support of the discussion carried out in the last section of this paper. Lapadu-Hargues (1945) made a study of the chemical composition of average metamorphic rocks. He selected seven groups of metamorphic rocks viz., Group I — Schistes sedimentaires; II — Schistes a serisite et micaschistes a muscovite; III — Micaschistes a biotite et muscovite; IV — Gneiss a deux micas; V — Gneiss granitoides, oeillès, a biotite seule; VI — Granites; and VII — Granulites. His comparison of the average composition of these groups is arranged in the above order, which is supposed to represent a series of increasing metamorphism. Unfortunately, the chemical analyses given include only eight important oxides. Moreover, he selected his data uncritically from available rock analyses in the geologic literature, without regard to the original composition of the sediments that were metamorphosed. Because of its importance to this paper, the writer has checked his data. The result was very disappointing.[1] Therefore Lapadu-Hargues' data can not be utilized.

Diffusion as a Basic Principle in the Interpretation of Petrochemical Changes.

All examples investigated above have indicated that 1) metamorphism of the rocks under consideration is not isochemical, but addition, subtraction and migration of material are evident; 2) petrochemical culmination of certain element ion, atoms, or molecules is a characteristic feature of the chemical changes; 3) concentration, as indicated by petrochemical culmination of certain elements, is correlated with the formation of the most stable mineral phases; 4) migrations of different elements are in different directions; and 5) overlapping of the fixed granitizing and basifying front exists to some extent, indicating their complementary nature.

The partial chemical potential and its derivatives (vapor tension, chemical activity etc.) vary with pressure, temperature, composition, size of minerals, and with the surrounding phases. Any gradients in these factors will create a chemical potential gradient along which the particular ion or atom of the mineral under consideration will migrate.

Applying the principle of diffusional migration, Perrin and Roubault (1939, 1949) H. Ramberg (1944 a; 1944 b, pp. 102—109; and 1946) and J. Bugge (1945, pp. 9—31) emphasized the importance of this process in petrogenesis. Barth (1936, p. 806) and Ramberg (1944 b, p. 104) also demonstrated the application of such principles in the interpretation of zoning and the origin of certain veins and pegmatites.

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[1] Looking over the analyses used in the average of shale from twenty seven sources (each analysis in turn may represent the average of several analyses from different authors), I found the following discrepancies: No analysis can be found as indicated by Nos. 2, 4 and 5. No. 8 gives a reference to gneisses instead of the average of five palaeozoic shales from America. Nos. 9, 10 and 11 are with references only given in terms of Niggli valus. These may be due to mistakes of cross-references given. Nevertheless, nos. 13 and 14 are typical schists instead of shales and no. 16 is a typical kyanite schist.

It is clear that the addition, subtraction and migration of material as shown in the above examples must have happened in one of the following ways: 1) leaching and precipitation by a circulating solution or gas of unknown composition along supercapillary and capillary openings, or 2) by diffusion of activated ions, atoms, or molecules without the aid of a moving condensate. A large pressure gradient is generally needed to cause a solution to flow or circulate continuously. Holser (1947, p. 395) in his study of the transport of material through various sizes of openings, concluded that in rocks with subcapillary openings, transport of matter by diffusion through a liquid medium along grain boundaries or through crystalline lattices is more effective than by flow of the condensate. It seems to the author that an additional criterion is at hand to distinguish between pure chemical diffusion and mechanical flow. If pure liquid is essentially stationary, migration and transport of material is not governed by the pressure gradient but by chemical potential gradients. Under such condition, the migration becomes highly selective, and the directions are not limited to the path of flow of the solution or the pore liquid.

Let us for a moment examine the pattern and requirement of movement of solutions through a rock mass of reduced porosity. We must remember that we are dealing with a rock where free channels for flow of solution are greatly limited. Solutions and gases can only move into areas of low pressure, but the complicated chemical changes in the examples described in this paper require migration of material in many directions. Furthermore, precipitation and solution of silicates by a moving liquid is governed by the law of mass action. This implies that large quantities of liquid solvent are necessary to effectively transport silicates. The sources of such large quantities, and the mechanism of flow through rocks of greatly reduced porosity and permeability are, indeed, mysterious. According to Holmes (1936, p. 321) it is mechanically impossible to separate 10 to 15 per cent of liquid from a crystalline mesh. The difficulty of squeezing out the pore liquid from a solid rock mass would be considerably greater. If great pressure is operating on a rock mass with 5 to 10 per cent of pore liquid, the whole mass is likely to be plastically deformed instead of driving out the pore liquid.

It is a well known fact that porosity is reduced rapidly with increase of depth of burial.[1] At a depth of about 5 km, the porosity of sediments is reduced to nearly zero. Deformation also reduces the porosity of clastic sediments (Rubey, 1930). Shearing easily destroys the shale laminae of the order of 1—500 μ thick (Kienow, 1949, p. 348) resulting in a mass of fine aggregate which favors transport by diffusion. But it is the permeability of rock that controls the effective transport and penetration of liquid condensates. Coarse clastics whose porosity is greatly reduced by diagenetically deposited mineral cement and secondary overgrowth together with pelitic sediments are all prepared to be more or less impervious in the beginning of metamorphic action. Recent data on the degree of cementation of clastic sediments and its relation to depths of burial should be of some interests in this respect.

In order to show that chemical changes as characterized by culminations are brought about by diffusion, let us examine again the widely quoted chemical data obtained by Adams on bricks (1930, pp. 153—161). A dead burned Austrian magnesite brick (no. 5) low in lime, and another brick (no. 6) of synthetic clinker made from dolomitic magnesite and mill scale (largely Fe_3O_4) were heated in a kiln for 60 hours to 1430° C and cooled gradually for four days to 150° C. The iron-rich no. 6 brick bent over and accidentally touched no. 5 brick at one point, thus developing three concentric zones a, b, and c in the no. 5 brick with zone c at the contact. The partial chemical analyses of the two bricks and these three altered zones are as follows:

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[1] Athy (1930) has computed the porosity of a shale from its depth of burial from the formula $P = p(e^{-bx})$, where P is porosity, p is average porosity of surface clays, b is a coefficient, and x is the depth of burial. He also found that an original porosity of 50 per cent of a shale was reduced to only 8 per cent at 8 000 feet below surface, and that shales at 6 000 feet below surface are not uncommon to have only 5 per cent of porosity. Assuming that the clay size particles of the shale are spheres and are close-packed, a rough estimate of the order of magnitude of the diameter of the openings at the depth of 6 000 feet with 5 per cent porosity is something of 200 mμ. With platy clay minerals it should be easy to see that pore space at depths hardly exists. The effective transport of matter through such pelitic rocks will according to Holser's deduction (op. cit.) necessarily be diffusion.

	SiO_2	Al_2O_3	Fe_2O_3	CaO
No. 6 brick	1.0	1.0	22.4	8.4
Zone c in no. 5 brick	0.6	0.5	17.2	4.0
Zone b in no. 5 brick	1.6	1.3	15.6	5.4
Zone a in no. 5 brick	*3.5*	*1.7*	12.4	*6.3*
No. 5 brick	2.3	0.9	8.3	2.4

The analyses show clearly the migration of Fe along its concentration gradient, whereas Si, Al and Ca culminated in zone a, farthest away from the point of contact. Migration of these ions evidently were mostly against their concentration gradient. The explanation is difficult for lack of mineralogical data. Could it be due to the development of dicalcium silicate or gehlenite as a more stable assemblage in zone a? Was it because Fe did not participate in any chemical reaction that it migrated along the concentration gradient as described by Fick's law? No matter what the explanation and the state of equilibrium, the diffusion and migration of matter took place.[1]

With this experience as a guide a summary discussion and interpretation of metasomatic rocks by diffusion can proceed by considering the chemical composition of the parent rocks, the temperature and pressure and their gradients under which alteration of rocks takes place.

In pelitic rocks and graywackes, rich in clay minerals, progressive metamorphism produces slate, green schists and eventually rocks of amphibolite and hornfels facies. Under the P—T conditions of the amphibolite facies, Fe, Mg, Ca, Ti, Mn and some Al will form biotite and amphibole, depending upon the amount of K, Na or Ca and H_2O available. Consequently there develops a surplus of Si which is a probable source of the associated quartz veins,[2] or else may serve as one of the granitizing agents. In the case of the basified schists of the Stavanger area, there are two ways of accounting for the desilication of no. II, the quartz-muscovite-chlorite-garnet phyllite:

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[1] Williamson (1949, pp. 739 and 741) pointed out that this evidence does not support the interpretation as advanced by Reynolds, Backlund etc. to be solid diffusion, i. e., diffusion through crystalline lattice.

[2] Goodspeed (1940, pp. 175—195) and Ramberg (1944 b, p. 104: 1949) have shown that the source of SiO_2 of some quartz veins are derived from the surrounding rocks by lateral segregation (diffusion).

a) with the aid of a moving solution and b) by diffusion. Wholesale removal or leaching of Si by a solution moving in the rock should introduce cations proportional to the removal of Si. But the culmination of Ca, Mn, and Fe are sporadic and rather independent of desilication. If the formation of amphibole and biotite is accepted as the cause of desilication, then basification is a differential process (the formation of stable mineral phases) and complementary to the formation of quartz veins and silicification in adjacent areas (the redeposition of unstable mineral components).

The examples above show that with Si, also Na, K and P are removed as a result of basification. They form what may be arbitrarily called the granitizing agents.

Basification is generally indistinct in arkose and quartzite. But the Dunan Jurassic Sandstone as altered by the granophyre shows a fixed basified front (fig. 3). This implies a concentration of cations from the surrounding rocks, and not isochemical contact metamorphism.

Sparagmites are also desilicated. The replacement of quartz by feldspars is clearly observed in the granitized quartzites of the Black Hills.[1] The original texture of the quartzites is retained. Feldspar grows along grain boundaries and cuts into grains of quartz, thus the total volume of silica is reduced.

The limestone contact of Mansjö Mountain, Sweden is an example of basification and decarbonation. Supplementing examples are amphibolites and skarn rock described by Barth (1928; 1948 c) and Bugge (1945, pp. 43—44 and 54 in gabbroidal rocks) where concentration of Na, K and Si in areas of low pressure forms pegmatites.

The basic Breven Dolerite Dike suffered profound chemical changes as indicated by the conversion of zoned plagioclase to unzoned more sodic plagioclase, and recrystallization of ortho- and clino-pyroxenes into amphiboles. Ca ions in the labradorite (An 54—62 %) were activated and went into minerals having a lower Ca-ion activity i. e., the newly formed amphibole. In similar manner ions such as Si, Al, K and some Na migrated into no. 5 and no. 6 to form potash feldspars. Such changes not only depend on the bulk composition of the original dolerite but also on the ions that were foreign to the rock itself. These foreign ions may either come from the adjacent rocks or the postulated intrusive bodies. The new condition set up chemical activity gradients that influenced the ions of the rock, bringing about the amphibolitization and basification of no. 4 and granitization of no. 5 and no. 6.

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[1] Chao, E. C. T., Some Aplogranite of Black Hills, S. Dakota, U. S. A. unpublished

Chemical changes of rocks induced by new P—T conditions and new chemical environments are, generally speaking, of two kinds: basification and granitization. A summary diagram of metasomatic alteration of rocks of various compositions is given in figure 10. Figure 8 illustrates various P—T conditions under which inclusions, aureoles and regional zones of rocks are altered.

Inclusions picked up by granitic magma are heated and the temperature soon will approach that of the gradually cooling granitic rock. The thermal gradient at that temperature was therefore essentially zero, so was the pressure gradient. All components of higher free energy in the inclusions went into the "melt" and what remained reacted with the "melt" to form the stable mineral phases (for example biotite and amphibole). The chemical changes seem to be controlled mainly by the chemical environment and the temperature and pressure of the granitic rocks which is cooling down slowly enough to develop the granular hollocrystalline texture (curve III, figure 8). Most petrologists would probably agree that large amount of diffusion has taken place in the alteration of such inclusions.

Contaminated granites which surround basified inclusions are usually desilicated as compared with uncontaminated granites. Chemical reaction of a closed system alone can not account for the desilication, because there is an apreciable loss of silica per unit rock cell of contaminated granite. The interpretation can only be that Si and some K migrated into the surrounding granite. Moreover the addition of Mg to the inclusions and the contaminated granite confirms that Mg-metasomatism has taken place.

The part of the altered rock not in immediate contact with the bulk of granite must be influenced solely by diffusion. The ions must move from the basified zone to the granitizied zone and vice versa in order to account for the changes undergone by the rocks of examples 1 to 5. In these examples, the mobilized material is seen in a sharply defined narrow zone of the country rock. This is probably due to a steep thermal gradient. Rapid cooling (as indicated by curve

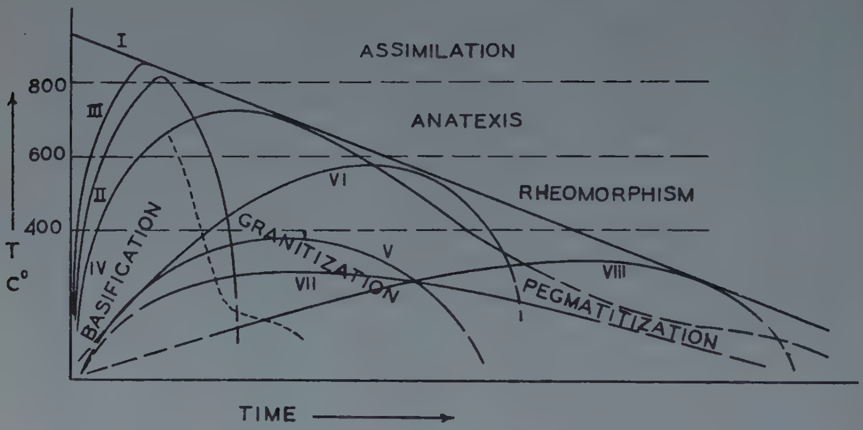

Fig. 8. — Schematic diagram showing qualitatively the rates of heating and cooling of the country rock of different examples of granitization and related petrochemical changes.[1] The curves represent the heating of the country rocks that surround the heat center. The slope of these curves is a vital factor which determines the state of equilibrium, rates of diffusion and pegmatitization, and the relative widths of "metamorphic" zones.

VI of figs. 8 and 9) arrests rather than promotes further diffusion. In such cases, equilibrium is not attained and there is little evidence of homogenization. This interpretation is supported by the geology of skarn rocks and by artificially produced zonary structures at contacts between silica melts and ceramic ware (attributed to

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[1] The schematic diagram is developed and expanded on the basis of the original concept of the cooling of host rock in relation to zoning as advanced by W. H. Newhouse and A. F. Hagner (1947, p. 1212).

A rapid rise of temperature, that is the steep slope on the left (II, III and IV) is supposed to give no opportunity for equilibrium between the incoming material and the country rock, the contact should therefore be sharp. A slow rise of temperature with a low maximum (V, VI, VII and VIII) will give more time for the diffusion and adjustment of the incoming ions and the ions in the country rock and produce a less sharp contact. A liquid phase probably will occur or start to form only when the maximum temperature is generally higher than 600° C (Göranson, 1932). The examples discussed in this paper demonstrated that basification-desilication will take place as the temperature rises. After the temperature has reached its maximum it falls in different manners and rates. As the temperature reaches its maximum, the mobility of material also becomes maximum, so that the dominant process as temperature falls would be that of feldspathization, formation of porphyroblasts in schists, development of zoned pegmatites at low pressure areas (in open

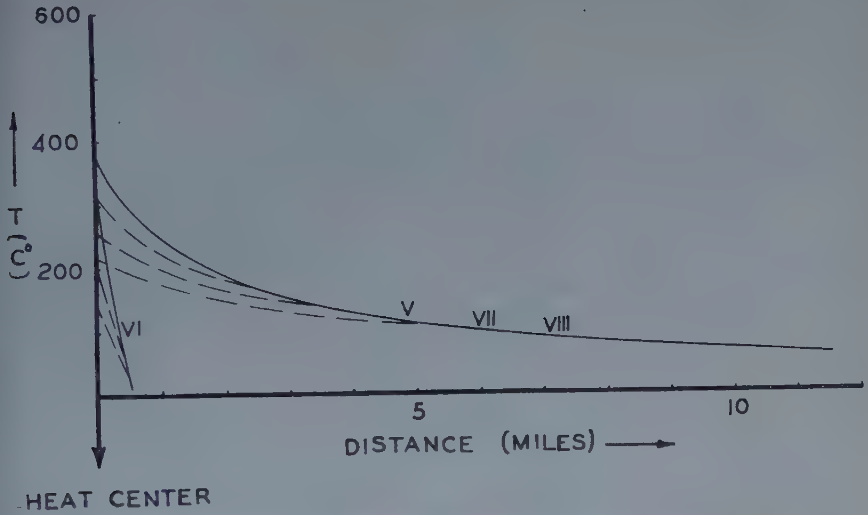

Fig. 9. — Various thermal gradients induced in the country rocks. The numbers as in figure 8. Dash lines indicate variation of thermal gradient with time.

solid diffusion due to a temperature gradient by Williamson, 1949, pp. 736—739).

The conditions for diffusion differentiation to produce granitization on a regional scale are quite different. Curves V, VII and VIII (figure 8) presuppose that granitization extends over a long period of time at much lower temperature than is necessary for remelting. Long time periods and a large amount of diffusion are necessary to

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structure) and pegmatitization with the formation of huge porphyroblasts in a fine-grained gneissic rock. The rate of cooling is partially governed by depth where this thermal wave takes place, that is the deeper it is, the slower the heat will be dissipated into the country rocks. Similarly the tighter the structural openings, the slower the penetration of heat.

I — Consolidation of a granite-liquid melt.

II — Hypothetical condition of injection. If the maximum is low (temperature), this condition, or the steepness of the curve shall represent that of veins formed by hydrothermal solutions, in fissures or low pressure areas.

III — Hypothetical condition of assimilation of sedimentogeneous inclusions.

IV — Similar to III, except that there is no assimilation.

V, VII, VIII — Regional granitization at relatively low temperatures and extremely slow rate of heating and cooling.

VI — Possible condition of granitized contacts.

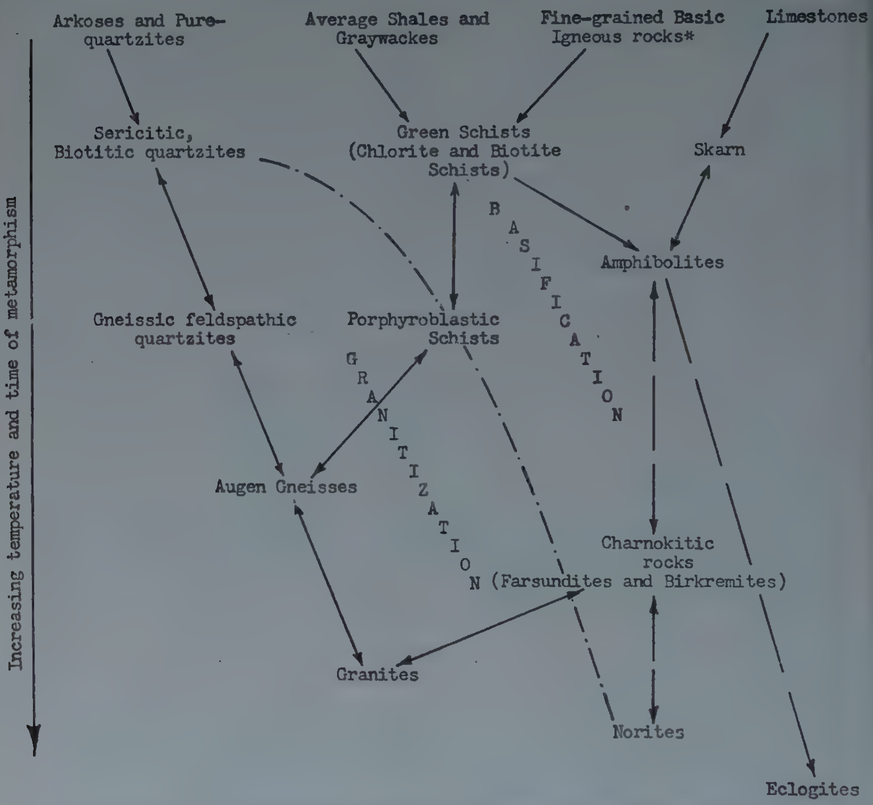
Arkoses and Pure-quartzites
Average Shales and Graywackes
Fine-grained Basic Igneous rocks*
Limestones
Sericitic, Biotitic quartzites
Green Schists (Chlorite and Biotite Schists)
Skarn
BASIFICATION
Amphibolites
Gneissic feldspathic quartzites
Porphyroblastic Schists
GRANITIZATION
Augen Gneisses
Charnokitic rocks (Farsundites and Birkremites)
Granites
Norites
Eclogites
Increasing temperature and time of metamorphism

Fig. 10. — Tentative Scheme of Diffusion Differentiation.

* No examples of granitization of coarse-grained basic rocks such as gabbro have been investigated here, but the trend of development is believed to more or less follow that of the fine-grained basic igneous rocks.

form the broad metamorphic zones at Stavanger, or in the sparagmites of Norway. The chemical reorganization is extend into lower temperature regions because dynamic metamorphism reduces the critical temperature at which recrystallization begins (Buerger and Washken, 1947). At a depth of about 5 km the rock temperature is normally about 105° C, and at 10 km about 210° C (Misener, 1949, pp. 125—133). During an orogeny the thermal gradient is probably appreciably raised; at great depths confining pressure (hydrostatic) produces structurally isotropic conditions, higher up the stress produces anisotropism (as indicated by schistosity etc.). Thus structural influence becomes dominant in the upper crust controlling the role and rate of diffusion in the process of granitization which always accompanies orogeny.

Pegmatites are found in places where structural discontinuities are indicated. Areas protected from shearing stress become centers of accelerated diffusion. As the areas are slowly heated and cooled, prolonged diffusion may give rise to huge porphyroblasts in rocks and to pegmatites.

To sum up: In rocks of greatly reduced porosity and permeability diffusion is a more important process than transport by a moving liquid condensate. Water between minerals is held by molecular attraction and remains essentially stationary. In the upper regions of the earth crust, comprehensive and shearing stress plays a much more important role in controlling the diffusion. More open spaces are available and diffusion is coupled with flow of a mobile condensate directing the travel of ions and molecules. With a stationary pore liquid the direction of migration of the diffusible ions depends on the partial chemical activity gradients of the several ions.

It is easier to accept a saturated essentially stationary pore liquid than a mobile solution moving through capillary spaces in the rock mass. Difusion in rock metasomatism takes place through zones of imperfect disordered mosaic crystals (fine aggregate) resulting from orogenic stresses (Reynolds, 1949, p. 247).

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I am greatly indebted to Prof. Tom. F. W. Barth for his inspiration and encouragement in the development of the interpretative part of this paper, to Prof. W. H. Newhouse and Prof. A. F. Hagner for their ideas on rate of cooling of country rocks and the importance of the structural elements in petrogenesis, and to Dr. Hans Ramberg for discussions concerning the thermodynamics of the diffusive process and for access to his unpublished papers.

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STUDIES ON TRILOBITE MORPHOLOGY

Part III. The ventral cephalic structures with remarks on the zoological position of the trilobites.

BY

LEIF STØRMER

Abstract. The third and last part of the studies on trilobite morphology deals chiefly with certain grinding series through the cephalic region of specimens of *Ceraurus pleurexanthemus* Green, collected by the late Dr. Ch. D. Walcott from the Middle Ordovician Trenton Limestone in U. S. A. Information is obtained on the ventral cephalic structures, the appendages in particular. The appendages, with the exception of the antenna, are found to be constructed on the same pattern as those in thorax and pygidium and the cephalic coxæ are not developed as true jaws such as generally assumed by the paleontologists. Criticism in connection with my previous descriptions and interpretation of the trilobitan appendage is met with. With regard to the zoological position of the Trilobita, the affinities to the Chelicerata are regarded as very probable. The Trilobita probably had a position not far from the ancestors of the Chelicerata, but whether they also stood near the ancestors of the Crustacea, still remains an open question.

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Introduction.

Part I of the present studies (Størmer 1939) dealt with the thoracic appendages of trilobites, and discussed the probable affinities between the Trilobita and the Chelicerata. In part II (1942) the larval development as well as the segmentation and sutures of the shell were discussed.

In the abstract of the last paper I indicated the appearance of a part III dealing with the cephalic appendages and presenting a general discussion of the trilobite affinities. During my studies it became apparent, however, that a general discussion of the trilobite affinities also involved a thorough study of several other fossils and recent arthropod groups. As the work proceeded, I found it appropriate to publish in a separate paper (1944) a general discussion of the affinities of a number of fossils and living arthropod groups, amongst them the trilobites, which I regarded as mutually related and belonging to one major group, the phylum Arachnomorpha.

Part III of the studies on trilobite morphology was therefore postponed, and the chapters on the affinities correspondingly abbreviated. The paper deals mainly with certain section series cutting through the head of *Ceraurus pleurexanthemus* Green from the Middle Ordovician Trenton Limestone, Trenton Falls, New York State, U.S.A. In connection with the description and discussion of the cephalic appendages it has become necessary to discuss some of my earlier described series and to meet certain criticism which has appeared since part I was published. In dealing with the affinities of the trilobites I have considered new evidence and new views published on the subject.

The material and methods applied are the same as those mentioned in part I (1939). The section series were carried out at Harvard University in U. S. A. in 1931—32, contemporaneously with those previously described. I wish also on this occasion to express my thanks to professor P. E. Raymond for his permission to use the collection and the facilities he offered me during the work. In connection with the studies and descriptions of the remaining series new glass- and wax models have been prepared.

In preparing the wax models I have had valuable assistance by Miss Lily Monsen. The photographs of the different models were taken by Miss Bergliot Mauritz and the drawings made by Miss Helga Lid, and Miss Lily Monsen under the supervision of the author.

Section series through the cephalic region of Ceraurus.

The section series are unfortunately not very complete and the preservation of the appendages is often less satisfactory. Nevertheless the remains give an impression of the original structures. The most complete series (H) comprises the frontal part of the head reaching backwards almost to the hind border of the labrum. Other series (J and K) demonstrate the remaining part of the head, but in these specimens the appendages are very fragmentarily preserved.

Ser. H.

(text-fig. 1—3 and pl. 1, 2).

Preliminary photographs of the wax model of this series have been published earlier (Størmer 1944, 1949).

The series comprises 64 sections. In preparing the magnified camera lucida drawings for the glass- and wax models it appeared that the magnification in the original photographs was not always quite the same. This had to be readjusted when preparing the magnified drawings. Succeeding drawings were compared and the adjustment of the magnification based on the known structures of the dorsal shell. As shown in the illustrations, the specimen appears to be slightly compressed at a right angle to the section-planes. This may be due to some inaccuracy in the magnification and in the measurements of the thicknesses of the sections.

The sections cut through an enrolled specimen. Best preserved are the sections through the anterior portion of the head. The sections are here almost vertical, forming an angle of 15° with the transversal plane. The most posterior section (no. 1) runs across the left lateral eye, cuts off the posterior border of the labrum and transverses the posterior margin of the cephalon just posterior to the right lateral eye, and crosses thoracic segments on the ventral side.

The shell. The sections give some information on the shell and its different sutures. The species *Ceraurus pleurexanthemus* was redescribed by Raymond and Barton (1913) and further morphological details were added by Whittington (1941) in his study of silicified trilobites from Trenton Limestone of Virginia. The morphology of the thoracic segments was treated in my earlier paper (1939).

As pointed out by the earlier authors the surface of the glabella is ornamented with larger and smaller tubercles. The larger ones occur more or less symmetrically in two rows diverging forwards on the frontal lobe. Walcott mentions (1921, p. 440, pl. 96, fig. 4) that his sections show each tubercle to be pierced by a canal perpendicular to the shell. Similar canals have been described in calymenids by Shirley (1936, p. 414) and in *Ceraurus* by Whittington (1941, p. 494).

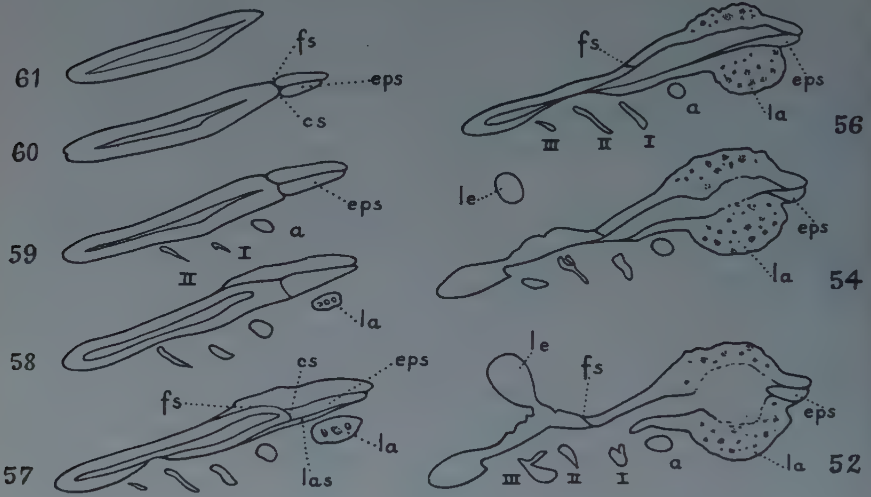
The convex middle body of the labrum has numerous small tubercles and corresponding canals penetrating the test. This is well demonstrated in sections 40—55.

The canals of the test are concentrated chiefly on the convex exposed surfaces of the glabella and labrum and might have contained sensory or tactile hairs as suggested by Shirley (1936).

The sutures of the test are also indicated in the sections. The course of the facial sutures are well demonstrated in Whittingtons silicified specimens. Raymond (1920, p. 60) and later Whittington (1941, p. 499) did not actually find an epistoma or rostrum. Raymond assumed the epistoma either to be entirely absent or being so narrow as not to be seen in specimens in the ordinary state of preservation. Whittington (1941, p. 499) did not recognize an epistoma in his material but assumed the presence of the plate from the shape of the head when placing specimens of cephalon and labrum in correct association to each other. An epistoma was demonstrated in *Ceraurus aculeatus* by Öpik (1937, pl. 17, figs. 2, 3).

As shown in text fig. 1 the cephalic sutures are well demonstrated in sections in the frontal portion of the head. The facial, epistomal and connective sutures appear in sec. 60. A transverse labral (hypostomal) suture appears in sec. 57 distinguishing a narrow epistoma in front of it. The epistoma, traceable on the left side down to sec. 46, thus forms a narrow transverse plate situated on the ventral part of the steep anterior border.

The appendages. The section-series cut through an enrolled specimen. Numerous sections of more or less fragmentarily preserved appendages are exposed in the photographs (pl. 1). The best preserved appendages occur in the cephalon on the right side of the labrum. The glass- and wax models prepared are confined to the cephalon and the appendages below it. The appendages below the thoracic test (opposite the labrum in the enrolled specimen on pl. 1) are too much dissolved to permit a closer identification. On the left side of the specimen (right side in photograph) a jointed appendage is demonstrated in sec. 1—6.

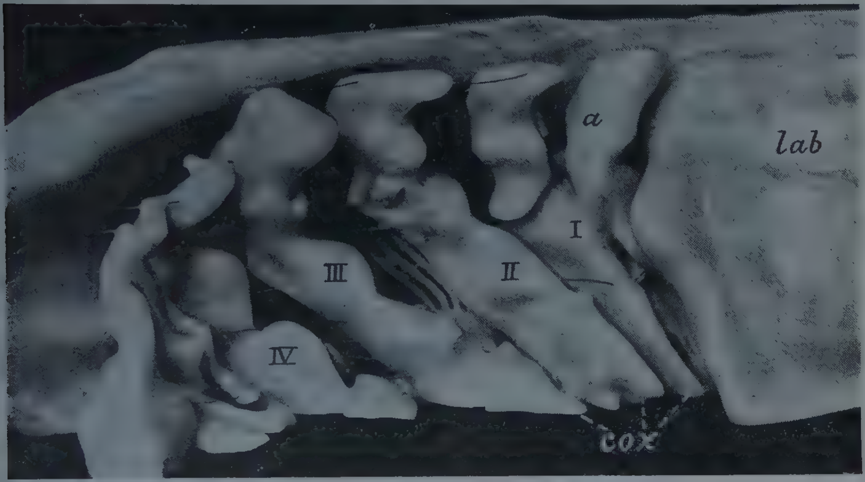


Text-fig. 1. *Ceraurus pleurexanthemus* Green. Part of grinding series H demonstrating the small epistoma. *a* = antenna, *cs* = connective suture, *eps* = epistoma, *fs* = facial suture, *la* = labrum, *las* = labral (hypostomal) suture. *I—III* = postoral appendages. 61—52 = number of sections.

The cavity between the glabella and the labrum is filled with calcite. This probably means that this part of the body was kept intact, not filled by the surrounding mud. It is difficult, however, to trace a definite body wall (integument) on either side below the glabella. The first sections (pl. 1) illustrate the indistinct borders. Below the cheeks of the cephalon the integument must have been destroyed since no calcite fillings indicate the border of the original softer tissues between the test and the ventral integument.

The distal portions of the cephalic appendages preserved on the right side of the labrum, are broken off along the anterior margin of the cephalon. The appendages are to a great extent dissolved and foreign bodies or calcite fillings rather, disturb the general picture. In the model shown in text-fig. 2 a longitudinal body on the 3rd appendages is removed. In the following the different appendages are described, starting with the first one in front.

The antenna (a). Dorsal to the lateral ear of the labrum an appendage emerges from the more or less vertical body wall between the glabella and the labrum (text-figs. 1—3a). As mentioned above the body wall is not distinct, but the general structures leave little doubt as to this anterior attachment of the appendage. From the



Text-fig. 2. *Ceraurus pleurexanthemus* Green. Part of wax model prepared from Ser. H. Ventral and slightly lateral view of cephalon. *a* = antenna, *cox* = coxa, *lab* = labrum, I—IV = postoral cephalic appendages, (comp. pl. 2).

base of the appendage an indication of two more or less plate-shaped formations extend backwards and unite with the body wall dorsal to the labrum. These formations do not seem to belong to the appendage or the primary structures at all.

From the body wall the appendage first has an antelateral direction, then turns anteriorly and slightly anteriomedially. The appendage has an elliptical almost constant cross-section, the smaller diameter being ½—⅔ of the greater. The model indicates (text-fig. 2 and pl. 2) that the appendage is somewhat twisted round its axis at the point when it changes its direction. Slight thickenings before and after the bend of the appendage might suggest a division of the appendage into three separate joints. Dorsal to the presumed second joint, just below the dorsal test of the cephalon, a plate-shaped thickening unites this joint with the next appendage (I). This thickening also appears to be a secondary formation.

The appendage described, being uniramous, and apparently multijointed, and attached to the body wall far in front below the protecting antelateral ear of the labrum, evidently represents the antenna or antennule (or first antenna) in other arthropods. This appendage has previously not actually been recognized in this genus.

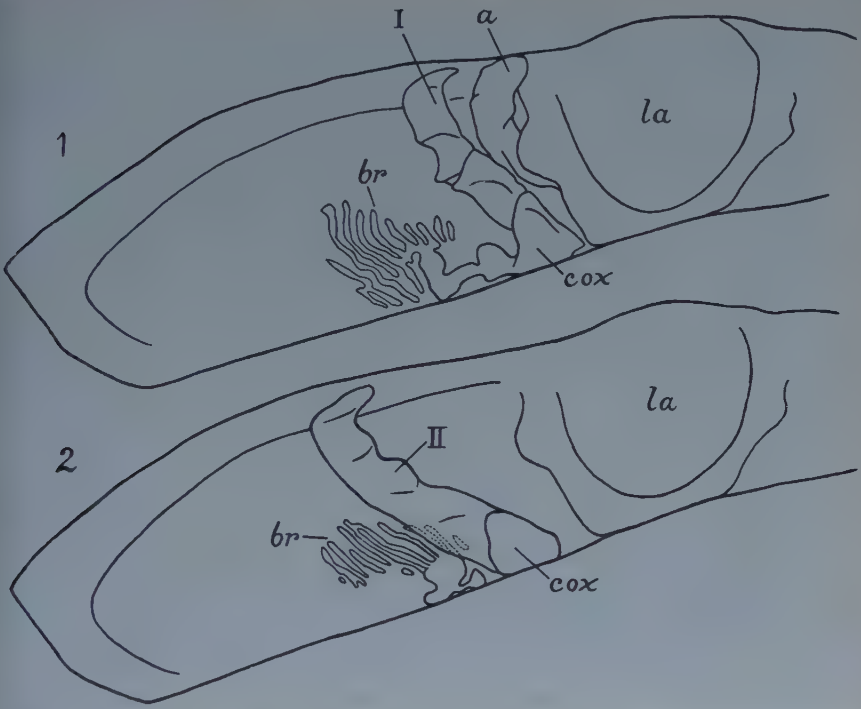
The first leg (I). This appendage is attached just behind the antenna (text-fig. 3, I), thus leaving hardly any space for a reduced "second antenna" such as suggested by some authors. As shown in text-fig. 1—3 and pl. 2, the first sections cut through the basal portion of the appendage. This basal portion communicates with the body wall, or more correctly the calcified space between the glabella and the labrum. This indicates that the appendage was attached dorsal to the postlateral portion of the labrum. The preservation does not permit a more detailed study of the basal structures.

A branchial ramus (preepipodite) is attached to the dorsal portion of the elongate basal body. The ramus is only fragmentarily preserved. The proximal joints seem hardly to have been reached by the section-series starting anterior to the posterior margin of the labrum. Judging from the more complete thoracic branchial rami earlier described (Størmer 1939), the first preserved joint might be the 3rd joint of the ramus. The 4th is almost completely dissolved and the 5th, forming the expanded distal joint, is but fragmentarily preserved. It forms a broader lobe with about 11 gills (text-fig. 3 *I*) directed anteriolaterally.

The coxa is narrow and slightly convex-concave with the concave side medially. The joint, which has a vertical position, is less tetrahedron-shaped than those described from the thorax (Størmer 1939, p. 177). The narrow basal portion might be due to the crowding up of the limbs round the mouth. Otherwise the coxa is much like those of the thorax. A basendite of the same type is present.

The first joint of the walking leg is separated from the coxa by a crossing furrow suggesting a jointline. The other joints of the walking leg are not distinct. Thickenings of the partly dissolved joints might suggest the positions of the articulating jointlines. Since the joints were partly telescoped one might assume that these portions were those least dissolved. Three transverse thickenings might suggest remnants of 3—4 joints, the fourth only represented by a very short basal fragment. The joints are flattened in a similar way as the coxa. The actual cross-section is, however, difficult to determine on account of the incomplete preservation. The first joint seems to be a little longer than broad, while the other ones seem to have a more equal length and width. A secondary cleft is seen in the second joint.

The second leg (II). This appendage has an extra body attached to the walking leg (pl. 2). In text-fig. 2 this is removed.



Text-fig. 3. *Ceraurus pleurexanthemus* Green. Outlines of individual appendages demonstrated in wax model of Ser. H. Ventral view of cephalon. *a* = antenna, *br* = branchiæ, *cox* = coxa, *la* = labrum. *I*—*II* = postoral cephalic appendages (comp. pl. 2).

This leg (text-fig. 3 *2*) shows more of the fourth joint of the walking leg, but less of the basal portion of the coxal region and the branchial ramus. The sections comprise only parts of the two distal joints of the branchial ramus. The gills are fairly well preserved, the fringe lying in a plane ventral to the gills of the first leg. The number of gills preserved is here also about 11. The coxa is similar to that of the first leg. The convex-concave joint is almost vertical and tilted somewhat towards the labrum. The distal border of the coxa is suggested by a transverse furrow just as in the first leg.

The walking leg appears to be divided by three transverse thickenings into four joints. The outlines of the joints are, however, little distinct. The leg having a fairly constant width, is strongly flattened, the greatest width being about twice the smallest one or more. The greater axis in the cross-section forms an acute angle of about

30°—40° with the horisontal plane, giving the walking legs the capacity of sliding over each other.

The third and fourth legs (III, IV). Only a small triangular portion of the coxa is included in the sections. Three fragmentary gills belonging to this appendage lie in a plane ventral to that of the gills in the second leg. The walking legs resemble those of the two anterior legs. Transverse thickenings indicate similar joints. A strong inclination of the leg at the third to fourth joints is indicated.

The last cephalic (IV) and the first thoracic leg (V) are much dissolved, but they appear to be similar to the three legs in front of them.

The section series described above has rendered valuable support to our general knowledge of the structures of the cephalic appendages in *Ceraurus*.

A pair of preoral uniramous antennae (or antennules) are attached to the body wall dorsal to the antelateral ears of the labrum. The 4 postoral appendages are built on the same pattern as those of the thorax, thus clearly demonstrating the uniformity of the appendages in different parts of the body. Only a slight specialization is indicated in the narrowness of the cephalic coxæ. The first pair of postoral appendages (II) are situated on either side of the posterior portion of the labrum which probably just covered the most median portion of the coxa of these appendages. The basendites of the cephalic coxæ are not developed as gnathites.

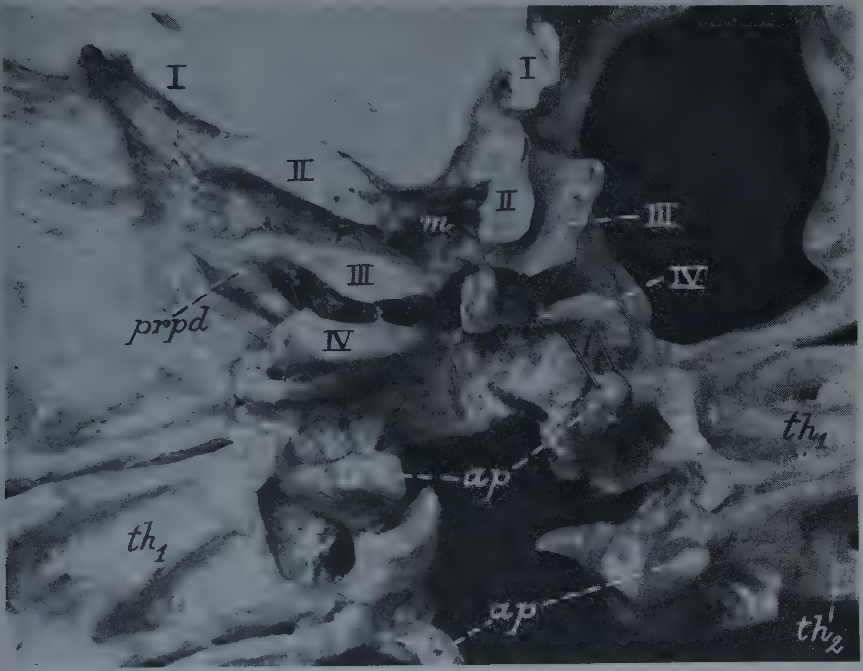
Ser. J.

Pl. 3 fig. 8, pl. 4, text-fig. 4.

This section series was partly dealt with in my previous paper in connection with the description of thoracic tergites (1938, text-fig. 6).

The 16 sections, running nearly parallel to the horisontal plane, cut through the dorsal portion of the cephalon and the main part of the thorax. In the cephalic region the most ventral section lies just dorsal to the posterior part of the labrum, the most dorsal section just above the right lateral eye and at the base of the left lateral eye.

The sections give some information on the structure and position of the posterior cephalic coxæ, structures not demonstrated in the



Text-fig. 4. *Ceraurus pleurexanthemus* Green. Detail of wax model of Ser. J. Ventral view of middle portion of cephalon and two anterior tergites. Only the basal portions of the cephalic appendages are preserved (comp. pl. 4). *ap* = apodemes for the attachment of muscles to the appendages, *m* = probable position of the mouth, *prpd* = preepipodite, th_1, th_2 = thoracic tergites.
I—IV = postoral cephalic appendages.

above described H-series. A glass- and wax model have been prepared of ser. J (text-fig. 4 and pl. 4).

The space between the glabella and the labrum is also in this specimen filled with calcite. The vertical posterior wall of the calcite-filled portion has a dorsal position in relation to the labrum and might suggest the position of the mouth.

The appendages. The basal portion of the first walking leg (I) is apparently traced on both sides of the calcite-filled area. The portion preserved forms a longitudinal body attached to the body wall (?) along the median side and having an anteriolateral direction similar to that of the coxa of the posterior cephalic appendages. The pronounced antelateral position might at first sight suggest a distinct preoral position, but one has to bear in mind that only the more dorsal portions of the cephalon is cut by the sections. The frontal portion including the antenna is not demonstrated in the series.

The second leg (II) is represented by the coxa preserved on both sides. Because of the oblique transverse section the appendage on the left side (right in photograph) appears to be stronger and reaches further back. The incomplete preservation does not permit a closer morphological study of the basal region. One notices, however, that the coxa forms an elongate, fairly narrow body attached to the postlateral portion of the body wall dorsal to the labrum. In ventral view the body appears to tilt slightly backwards. The median acute border of the coxæ, the basendite, does not reach the median line.

The coxa of the third leg (III) is not connected with the calcite-filled central portion. The coxa is elongate with the long axis forming an angle about 60° with the median line and is tilted backwards (in ventral view) in the same way as the coxa of the second leg. Possible fragments of the basal joint of the branchial ramus is seen lateral to the coxa on the right side (left in ventral view). The coxa of the fourth appendage (IV) has a more transverse position than those in front, forming an angle of 80°—90° with the median line. The elongate coxa on the right side is nearly vertical, not tilted backwards as those in front. The median borders of the three posterior pairs of the coxa lie more or less on a line and those on the right and left side are well separated from each other. The coxæ of the succeeding thoracic segments are not preserved.

The relation between the dorsal apodemes (gabellar furrows) and the cephalic coxæ are demonstrated. The fourth coxa, or rather a precoxa dorsal to it, is attached just below the posterior glabellar apodeme (belonging to the occipital ring) just as the precoxa of the appendages of the thorax (Størmer 1939). The third coxa has a more posterior position than the corresponding apodeme or glabellar furrow. The tilting of the coxa might, however, be seen in connection with this. The same is the case, and more so, with the second coxa which is pushed backwards so that it has a position partly below the succeeding apodome. Since only parts of the first coxa is preserved, its connection with the dorsal test is less distinct.

The section series described illustrates the position of the cephalic coxæ in relation to the dorsal test. Although the coxæ are incompletely preserved not permitting any closer study of the basal coxal region, they show that their basendites did not meet in the median line. The position of the coxa in relation to the corresponding apodemes on the glabella (glabellar furrows) indicates an inclination backwards of the basal portions of the appendages.

Ser. K.

(pl. 3, fig. 7, 9, text-fig. 5).

The specimen sectioned is not enrolled, but like many other specimens of *Ceraurus* in the Trenton Limestone, it shows a characteristic bend along the joint-line between cephalon and thorax. The 22 oblique transverse sections cut through this arched dorsal portion of the body. The most dorsal section (22) cuts off the median and left portions of the anterior tergites, while the most ventral one (1) runs through the posterior portion of the cephalon, from the left lateral eye across the glabella to the posterior margin just behind the genal angle on the right side, cutting through three tergites on the right side and four on the left.

The preservation is not satisfactory. The remnants of the appendages give little information of the morphological details. A glass- and wax model were prepared of the series, the former being steriographically photographed (text-fig. 5).

The shell. The sections through the posterior portion of the glabella show very well the larger tubercles penetrated by a central canal such as described above under ser. H. The deep apodemes of the two posterior glabellar furrows (the posterior one in the occipital furrow) are demonstrated. These structures are very distinct also in ser. J (pl. 4 *gf*) and in Wittington's silicified specimen (1941).

The ventral integument. In *Triarthrus* Beecher (1895) described the ventral integument which he found to be segmented below the axis (mesotergite). Similar structures are indicated in Walcott's sections of *Ceraurus* and *Calymene* from the Trenton Limestone (Walcott 1918, 1921).

In the specimen sectioned parts of the surface of the ventral integument seem to be preserved below the axis. Below the two posterior segments of the cephalon and the anterior tergite of the thorax, the integument is divided in segments, each forming a roll apparently on account of the bending of the body at this point.

The appendages. Also in this specimen the space below the glabella is filled with calcite. On the left side (right side in ventral view) the remnants of the coxa and basal part of walking legs of the posterior cephalic appendages (III and IV) are indicated. Anterior to the third coxa (III) a triangular portion probably belongs to the calcite-filled space rather than representing a dislocated anterior coxa. The fourth coxa has a concave anterior border and is tilted slightly forward probably on account of the crowding up of the coxa due to the inclination of the head. The slenderness of the coxæ, at least those of the two anterior thoracic segments, may to some extent be due to incomplete preservation. The thicker basal portions with their blunt median border might suggest the presence of precoxæ.

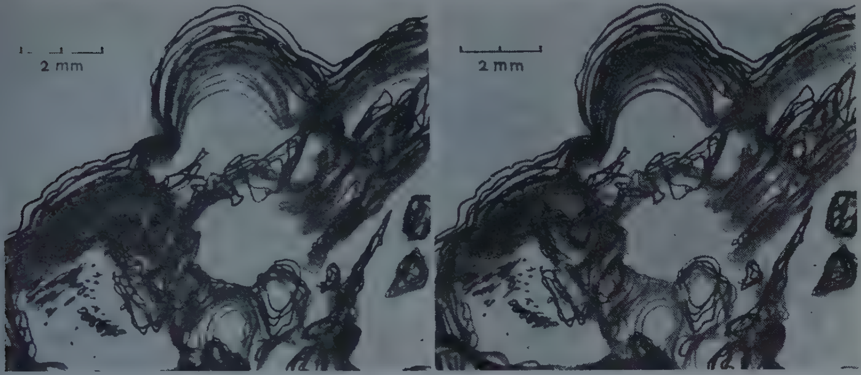
On the right side (left side in ventral view) only the more dorsal portions of the appendages are demonstrated. While both the basal and more distal portions of the appendages on the left side were directed anteriolaterally, the basal joints on the right side are directed postlaterally and the more distal ones anteriolaterally. It is characteristic that the median basal portion of the coxal region is blunt transverse, not wedge-shaped such as in the typical coxa. The same is found in the thoracic appendages of ser. C (text-fig. 8) and in sections figured by Walcott (text-fig. 10). This basal portion I have interpreted as a precoxa (Størmer 1939). The branchial rami attached to the precoxæ (?) of III—V, turn almost at a right angle forwards. The exact structure of the rami is not demonstrated, but a connection with fragments of branchiæ is indicated.

The described section-series demonstrates the segmental character of the ventral integument below the axis. It also furnishes some information on the structure and position of the posterior cephalic and the anterior thoracic appendages. The presence of a medially broader portion of the basal coxal region supports the assumption of the presence of a precoxa.

Ventral cephalic structures in trilobites.

General structure of the arthropod head.

The frontal portion of the arthropod body is covered by a continuous exoskeleton. This part of the body, the head, prosoma or cephalothorax, is separated from the rest of the body by a transverse joint-line. As pointed out particularly by Snodgrass (1938) the head



Text-fig. 5. *Ceraurus pleurexanthemus* Green. Stereoscopic photograph of glass model of Ser. K. Transverse section of enrolled specimen (comp. pl. 3, fig. 7).

(prosoma or cephalothorax) does not include the same number of somites in the various arthropod groups.

The segmentation of the frontal portion of the arthropod head is difficult to make out, but some information has been obtained by detailed studies of the nervous system. The arthropod brain is normally divided into three parts: the protocerebrum, deutocerebrum and tritocerebrum. The gangliæ of the two first parts are preoesophageal (preoral), while the gangliæ of the tritocerebrum are postoesophageal (postoral), belonging to the ventral nerve-cord, thus being of the same type as those enerving the somites (segments) of the rest of the body. We may easily distinguish a tritocerebral somite, but it is difficult to point out a division into separate somites of the preoral portion of the head. As pointed out in part II (1942, p. 120—123) the protaspis larva in primitive trilobites may suggest a division into two parts, the preantennal segmental complex and the antennal segment or somite. Also the presence in certain larvæ, of rudimentary preoral coelomic sacs and rudimentary antennæ in front of the antennæ enerved from the deutocerebrum, may suggest the presence of several segments in the preoral portion of the head. Studies on the arthropod brain have on the other hand lead to the conception that the preoral portion of the head was primarily undivided, differing considerably from the postoral portion of the body. Future studies, not the least on fossil forms, may settle this problem, but at present it seems useful to regard the frontal portion as one unit and apply the term acron to this primarily preoral portion of the head (Vandel, 1949, p. 97).

A head consisting of the acron and 4 postoral somites is most common in the Arthropoda. It is found in trilobites, indicated in the embryo of the Xiphosura, occurs in most of the Entomostraca, and in the Leptostraca, Amphipoda and Isopoda among the Malacostraca, and is a constant feature in the head of Myriapoda—Insecta.

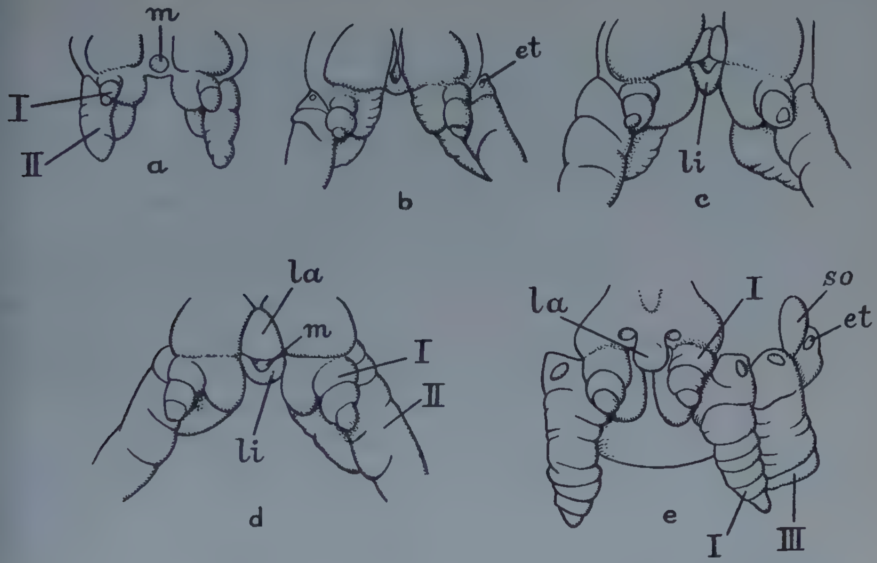
As pointed out by Snodgrass (1938, p. 107) this type of head hardly represents an early stage in the development of the Crustacea. A head composed of the acron and one postoral somite only, the so-called protocephalon, occurs in Anostracan Branchiopoda and in larval stages of many other forms. It is not certain whether the crustacean nauplius comprises the acron and two postoral somites, or possibly one or two more somites (Størmer 1944, Vandel 1949).

A head, or more correctly a prosoma composed of an acron and six postoral somites, is found in the Arachnida. In the Xiphosura the transverse joint-line between the prosoma and the metasoma or abdomen, crosses the primary more oblique segmentation, leaving a prosoma with six—seven postoral somites, the sixth and seventh belonging partly to the prosoma and partly to the metasoma.

The cephalo-thorax of the Malocostraca includes a considerable number of somites.

Turning now to the ventral side of the head, we find considerable variation in the development of the appendages and the structures connected with the mouth.

The mouth has a ventral position. A more frontal (terminal) position in the Arachnida is a secondary formation. In front the mouth is bordered by an upper lip or labrum (= hypostoma in trilobites) enervated from the tritocerebrum and therefore hardly representing a separate somite such as suggested by some authors. The ontogenetic development of the mouth and the labrum is recently demonstrated by Kästner (1948) in the Pedipalpi of the Arachnida (text-fig. 6). It appears that the labrum is primarily paired, being formed by the fusion of the two sides of the longitudinal mouth-slit. At the base (in front of) of the labrum a special plate, an epistoma, may be developed. The labrum forms a broad overhanging plate in certain arthropods such as in the Branchiopoda and particularily in the Trilobita, but in most groups it is reduced to a narrow plate between the appendages crowded around the mouth.



Text-fig. 6. The ontogenetic development of the mouth and frontal appendages in the Pedipalpi among the Arachnida. *Thelyphonus candatus.* (After Kästner 1949.) *et* = ecdysial tooth, *la* = labrum, *li* = lower lip, *m* = mouth, *so* = sensory organ, *I—II* = first and second postoral appendages.

A lower lip or postoral plate may form the posterior border of the mouth. According to the ontogenetic development of the Pedipalpi (text-fig. 6) the lower lip develops as a swelling of the integument just behind the mouth. This would indicate that the lower lip is formed by tritosternum i.e. the sternum of the first postoral somite (I). Such a structure is indicated in the Palpigradi, but in other arachnids the lower lip (underlip) is formed either by more posterior sternites, or by the coxæ of the cephalic appendages (Snodgrass 1948, p. 14). In the Acarina the structure is called hypostoma, a name which might easily be confused with the trilobite hypostoma meaning the labrum. The Xiphosura and the Eurypterida have an endostoma forming the posterior wall of the mouth opening. In the Eurypterida a larger ovate plate, the metastoma, forms a postoral plate below the endostoma. The metastoma is probably homologous with the chilaria of the Xiphosura, thus representing the rudimentary seventh postoral appendages. In the Myriapoda—Insecta the lower lip, the labium, is formed by the fusion of the bases of the second maxillæ (IV).

It is evident that the lower lip in different groups of the Arthropoda is developed from very different structural elements. It is therefore difficult to apply one term such as the labium for all types of arthropods. The more neutral term lower lip or postoral plate seems appropriate until a common name is found.

The cephalic appendages vary considerably both with regard to position and structure. Primarily only the first antennæ or antennules (a) have a preoral position. The other appendages are attached to the sternum on the ventral surface of the transverse somites behind the mouth. This development is found more or less in the Crustacea and Insecta. In the Chelicerata on the other hand, a considerable displacement of the appendages in relation to the mouth has taken place. The preoral antennæ are completely reduced. The chelicera forming the first appendages, belong to the tritocerebral somite and are thus primarily postoral, but in the Chelicerata these appendages (I) have a distinct preoral position. Even the second and third pair of primarily postoral appendages have a preoral position in the Xiphosura. Ontogenetic studies (text-fig. 6) have shown this to be due to a backwards migration of the labrum and then also the mouth in relation to the position of the appendages.

Primarily the appendages of the arthropod head were set well apart demonstrating the sternites in the middle between them. In many groups, however, a particular development of the coxæ reduces and conceals the sternites. Especially when the bases of the appendages form parts of the feeding organs, the structures differ considerably from the original one or the primitive conditions demonstrated in the larva.

The development of the feeding organs of the Arthropods depends on the kind of food they are consuming. The arachnids absorb liquid food only and have hence no jaws developed. Because of the liquid diet a special sucking apparatus and a preoral cavity formed by the coxæ develop in connection with the mouth.

Nor the Xiphosura have true jaws, but the powerful coxæ with their spiniferous median margins were probably able to serve to some extent as masticatory organs. The prey is seized by the legs and the chelicera, partly crushed by the spiniferous coxæ and the blunt median process of the sixth appendages (VI), but the chewing or grinding of the food take place in the proventricular gizzard. (Snodgrass 1948, Fage 1949).

In the Eurypterida the masticatory function of the prosomal coxæ were somewhat more advanced. In the large forms in particular, the median border of the powerful flat coxæ were provided with strong teeth and knobs. With their only partly masticatory function, the cephalic coxæ of the Chelicerata cannot, however, be regarded as true jaws comparable to those in Crustacea, Myriapoda and Insecta.

In the Crustacea, Myriapoda and Insecta the second pair of postoral appendages (II) are transformed into powerful jaws, the socalled mandibles. Also the third and fourth pairs of appendages, the first and second maxillæ (III, IV), serve as accessory feeding organs. In the maxillæ the distal portion of the appendages are not reduced to the same degree as is the case in the mandibles.

The cephalic limbs are distinctly biramous in most Crustacea. Somewhat similar limbs are found in the Trilobitomorpha (trilobites and certain other extinct arthropods), but the limbstructures of these forms seem in my opinion hardly to be homologous with those of the Crustacea. A biramous appendage built on the same plan as in the Trilobitomorpha is indicated in the Xiphosura and probably in the Arachnida (Størmer 1939, 1944). A biramous appendage is not present in the Myriapoda—Insecta. Certain structures recalling biramous appendages exist in certain forms, but hardly significant (Størmer 1939, p. 258—261). The biramous legs of the Trilobitomorpha and Chelicerata are characterized particularly by the possible presence of a precoxa, a powerful coxa, a gill-branch with plate-shaped gills attached to the presumed precoxa, and a walking branch (telepod) normally with a patella intercalated between the femur and tibia. In the Crustacea, on the other hand, the two branches of the appendages are attached to a basal stem, the protopodite or sympod, the outer branch, exopodite, has setæ, but no gills, the inner branch, the endopodite, has no patella.

After this general introduction we shall discuss the ventral cephalic structures of the trilobites.

Ventral cephalic structures in Trilobites.

As soon as the appendages of trilobites became known, particular interest was attached to the problem of the cephalic appendages, their structure, function and relation to the mouth.

Already Walcott's (1881) studies on thin sections of *Calymene* and *Ceraurus* gave some information, and the descriptions by Mickleborough (1883) and Walcott (1884) of appendages in *Isotelus* might also be mentioned.

Not until the discovery of the beautifully preserved specimens of *Triarthrus* a more detailed study of the cephalic appendages could be carried out. After having cleaned a considerable number of the pyrite specimens, Beecher (1895) was able to present a description and preliminary reconstruction of the cephalic appendages. In addition to the appendages he describes the ventral integument and postoral plate.

Beecher interpreted the cephalic appendages as antennules, antennæ, mandibles and two pairs of maxillæ, just as the appendages in the head of crustaceans. He assumed that the coxæ of the cephalic appendages in trilobites served as gnathites, the inner edges on gnathobases of the coxæ being "apparently finely denticulate".

Beecher's work was completed by Raymond (1920). He found the cephalic coxa of *Triarthrus* to be less like those of the thorax, otherwise his studies corroborated those of Beecher. Like Beecher, Raymond expressed the definite opinion that the cephalic coxæ (coxopodites) served as gnathites. This opinion seems to a certain extent to have been influenced by the conception of a crustacean nature of the trilobites. As evidence in favour of a gnathic function of the coxæ Raymond describes (1920, p. 152) the occurrence in one specimen (only) of the inner edges of the cephalic coxæ as being "distinctly nodulose, and roughened for mastication".

Valuable information on the structure of the cephalic appendage was presented by Walcott in two papers (1918, 1921) dealing chiefly with the appendages in *Olenoides*[1], *Calymene* and *Ceraurus*, but also describing other known forms. Concerning the structures of the cephalic appendages Walcott's studies largely conform with those of Beecher and Raymond. Walcott also interprets the cephalic coxæ as gnathites and meant to find traces of spines on the inner (median) margin of the coxa (1918, pl. 26, figs. 4, 15).

The works of Beecher, Walcott and Raymond are valuable not the least because of the many fine illustrations forming important sources of information.

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[1] As pointed out by Kobayashi (Journ. Fac. Sci. Imp. Univ. Tokyo, Sec. 2, 4, 2, p. 154. 1935) the name *Neolenus serratus* (Rominger) has to be replaced by *Olenoides serratus* (Rominger) since the genus *Neolenus* Matthew 1899 hardly differs from the genus *Olenoides* Meek 1877.

The labrum, mouth and postoral plate.

With its solid test the labrum or hypostoma is commonly preserved in the trilobite specimens. Numerous forms have been described belonging to many different genera. It might be mentioned that among certain families the labrum is rarely preserved. This is the case i. g. with the Cryptolithidae and Harpidae. In the appendage-bearing specimens of *Cryptolithus* the small labrum is only fragmentarily preserved (Raymond 1920, p. 62), indicating a less solid test.

The size and shape of the labrum vary considerably. In certain species ,such as *Ptychopyge angustifrons* Dalman (Brøgger 1886 pl. 3, fig. 42) and *Cheirurus (Crotalocephalus) gibbus* (Barrande 1852) the labrum reaches almost to the hind border of the cephalon, in the case of the former, however, with a deep median cleft in the plate. The labrum is in front attached along the labral (hypostomal) suture. A possible independent movement of the labrum has been discussed by various authors (Brøgger 1886, Öpik 1929, Stubblefield 1936. p. 410 and Whittington 1941, p. 514—515). Only a slight vertical movement and a possible vibration seems to have been able to have taken place.

The ontogenetic development of the labrum is little known. Whittington (1941, p. 496, pl. 72, fig. 2, text-fig. 1) has found a metaprotaspis of *Flexicalymene senaria* (Conrad) with a labrum provided with four pairs of short, thick spines.

The mouth has not actually been recognized in trilobites, but the ventral surface (the ventral membrane) of the cephalon as well as the position of the postoral plate might give some information of its location. Some of Walcott's sections of *Calymene* in particular (1921, pl. 101, figs. 1—4, pl. 105, fig. 2) show the ventral membrane curving in beneath the labrum, suggesting the position of the mouth slightly in front of the posterior margin of the labrum. Series J and K described above suggest a similar position. A backwards displacement of the mouth is discussed below in connection with the appendages.

The postoral plate, "metastoma" or labium was first described by Beecher (1895) in Triarthrus: "The metastoma is generally clearly shown as a convex arcuate plate just posterior to the extremity of the hypostoma. On each side, at the angles, are two small elevations, or lappets, which suggest similar structures in many higher

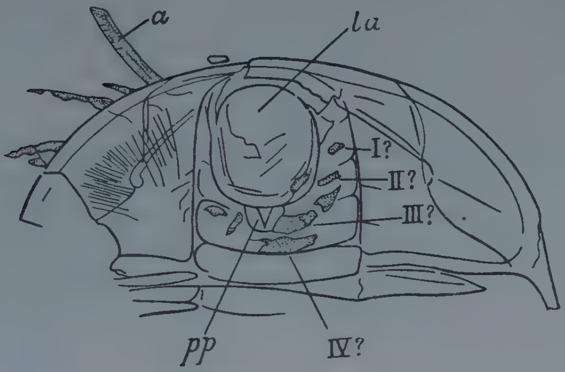
Crustacea, and apparently represent the entire metastoma in *Apus* and some other forms". Raymond (1920, p. 42) remarks that the postoral plate (metastoma) is larger and more nearly circular than Beecher's earlier preparations led him to suppose.

In one of his thin sections of *Ceraurus* (not *Calymene*) Walcott (pl. 27, fig. 12) meant to trace a section of a postoral plate between the cephalic coxæ. The structures are, however, little distinct and no trace of a postoral plate is found in the material sectioned by me.

Examining the collections of *Olenoides serratus* (Rominger) in U. S. National Museum in Washington, I noticed one specimen, previously not described, which has the postoral plate fairly well preserved (text-fig. 7 and Størmer 1949 fig. 11 D). The dorsal test of the cephalon is broken off demonstrating the labrum, postoral plate and fragments of the appendages. Just behind the posterior margin of the labrum, the semicircular postoral plate is surrounded, except along the transverse frontal border, by a narrow rim. The lateral part of the plate lies ventrally in relation to one of the coxæ, probably belonging to one of the third cephalic legs (III). This indicates that in ventral view the lateral portions of the postoral plate covered parts of the cephalic coxæ.

Judging from the position of the postoral plate in trilobites it is natural to regard it as a sternal formation. Probably the main part of the frontal sternite (or sternites) is transformed into a postoral plate or lower lip with its lateral lappets covering to some extent the median portions of the coxæ.

As mentioned above the postoral plate in trilobites is probably homologous with the lower lip in primitive arachnids and with the endostoma of the Xiphosura—Eurypterida. The postoral plate in trilobites has been described as a metastoma, but since this organ in the Eurypterida probably represents the modified appendages of the seventh postoral somite, this name is less appropriate (Størmer 1944. p. 32). In previous papers (1944 and 1949, p. 174) I have used the name labium for the postoral plate in trilobites. Since the term labium is a well known structure in the insects, meaning a lower lip formed by the second maxillæ, this term is hardly appropriate. Until more details are known concerning these structures in trilobites, I prefer provisionally to use the more neutral term postoral plate for the structures mentioned.



Text-fig. 7. *Olenoides serratus* Rominger. Cephalon with the postoral plate and fragments of appendages (dotted). *a* = antenna, *la* = labrum, *pp* = postoral plate. *I—IV* = postoral cephalic appendages. Specimen from the Middle Cambrian Burgess shale, British Columbia, Canada. Walcott's collection. U. S. Nat. Museum.

The appendages.

The antennæ are known more or less in species of the genera *Olenellus, Olenoides, Kootenia, Ptychoparia, Cryptolithus, Triarthrus, Phacops, Asteropyge* and *Ceraurus* (comp. Størmer 1939, p. 153—154). The antennæ have a preoral position, being attached to the bodywall on either side of the frontal portion of the labrum. The attachment of the antennæ is demonstrated in the sections of *Ceraurus.* The antenna is attached to the more vertical integument above the labrum and the point of attachment is evidently protected by the lateral ears of he labrum. Similar ears in the labrum of other trilobites may thus suggest the location of the antenna in these forms. Special indentations in he lateral borders of the labrum, i. g. in *Cheirurus ? fortis* Barrande (Prantl and Pribyl 1947, pl. 2, fig. 1—2) probably indicate the position of the antennæ.

The uniramous, multijointed antennæ differ but slightly in the different genera known. Reconstructions of *Triarthrus* (Raymond 1920, text-fig. 10) indicate a comparatively long and strong basal joint of the antenna. In *Ceraurus* this seems hardly to be the case. The antennæ of *Cryptolithus* have longer joints than in other forms and the specimens preserved have the antennæ directed backwards.

The position and structure of the antennæ in trilobites strongly indicate these appendages to be homologous with the antennules (or first antennæ) in crustaceans and with the antennæ in insects, thus being preoral appendages enerved from the deutocerebrum.

There are no signs of a reduction of a second pair antennæ such as suggested by Öpik (1937).

The four biramous appendages occupy most of the space on the ventral side of the head. Beecher (1895) showed that the posterior pairs of appendages and apparently also the anterior ones in *Triarthrus* were biramous and built on the same pattern as those of the thorax and pygidium. The cephalic appendages in *Olenoides* are not well demonstrated. The present material of *Ceraurus* presents new information on the structures of the cephalic appendages in this genus. The sections demonstrate four pairs of legs mutually much alike. The frontal ones being only somewhat smaller than the pairs further back. The section series have shown that also the first and second pairs of cephalic appendages are provided with a branchial ramus (preepipodite) attached to the basal portion of the appendage.

The present studies verify the current conception of the trilobite head having one pair of preoral uniramous antennæ and four pairs of postoral biramous appendages built on the same pattern as those on the thorax and pygidium.

Raymond (1920 p. 42) found the cephalic coxa of *Triarthrus* to be distinctly different from the coxa of the thorax. He also assumed (l. c. p. 67) the two anterior pairs of cephalic appendages in *Calymene* and *Ceraurus* to be reduced because of a lack of function in connection with a backwards migration of the mouth in these genera. Concerning the last mentioned genera the present studies have shown this not to be the case as mentioned below.

With regard to the development of the cephalic coxæ in *Triarthrus,* both Beecher's and Raymond's reconstructions are chiefly based on specimen 211 (Raymond 1920, pl. 2, fig. 5, and Walcott 1921, p. 104, fig. 15). In this specimen the coxæ on either side are overlapping each other forwards, exposing their flat posterior surfaces. This give the impression of the cephalic coxæ being considerably stronger than those on the thorax. As I pointed in part I (1939, p. 204), Raymond's presumed difference in the development of the cephalic and thoracic coxæ might to a large extent be due to the thoracic coxæ having a more vertical position and therefore appearing more narrow and less strong in ventral view.

As mentioned above the cephalic appendages appear to be mutually alike showing no individual specialization. This is demonstrated in section series H of *Ceraurus* where the biramous first postoral appendage is preserved. The first coxa is considerably flattened and slightly concave-convex with the concave surface on the antemedian side. No postlateral process is apparently developed such as in the thoracic coxæ, but the short endobase appears to be of the same type as that found in the thorax. There is no sight of a long median "gnathite" provided with teeth. The lack of a spiniferous or nodolous median margin of the cephalic coxæ might to some extent be due to incomplete preservation, but on the other hand the general correspondance in structure with the coxæ of the thorax hardly speaks in favour of the presence of such structures. Walcott (1918, pl. 26, fig. 4, 15) figures and describes certain structures which he interprets as spines on the inner (median) margin of the coxæ. Having studied Walcott's original sections of *Ceraurus* and *Calymene* I am little convinced, however, of the primary nature of the spine-like structures occurring particularly in his less well-preserved specimens. In several specimens the margins of the test are partly dissolved and drawn out into "threads". The same was the case with the gills (Størmer 1939, p. 187—188).

Nor the other trilobite genera seem to show distinct traces of special teeth, denticles or knobs on the cephalic coxæ. The spines on the cephalic coxæ of *Olenoides* appear to be like those on the thoracic coxæ. In one specimen of *Triarthrus,* Raymond (1920, p. 152) describes the inner edges of the cephalic coxæ as "distinctly nodulose, and roughened for mastication", but this single case, hardly represent any strong evidence in favour of the development of special gnathites.

As mentioned in part I (1939, p. 205—206) a faint indication of a transverse line across the base of the cephalic coxæ is suggested in specimens of *Triarthrus* figured by Raymond. The line might indicate the presence of a precoxa such as suggested in the thorax.

The position of the cephalic coxæ is not quite the same in the different trilobite genera. In *Triarthrus* the coxæ have an almost transverse position such as in the thorax, only the two frontal ones tend to have a more antelateral direction. In *Ceraurus* the cephalic coxæ turn gradually forward when passing from the fourth to the first legs. Because of the change in the direction of the coxæ the median portions are crowded together leaving little space in between the individual coxæ. At the same time the coxæ of the frontal pairs of appendages are tilted backwards. The general structures suggest a backwards migration of the mouth in trilobites. The migration is less pronounced in *Triarthrus* where the coxæ are more transverse and tend to be tilted forwards instead of backwards. A posterior migration of the mouth is also suggested in the dorsal segmentation of the trilobite larva as pointed out in part II (1942, p. 122). A similar but more pronounced backwards migration of the mouth is characteristic of the Merostomata as mentioned above.

The cephalic coxæ just like the thoracic ones are set well apart, having, as discussed below, no possibility of meeting each other along the median line.

The feeding organs of the trilobites.

Having described the ventral cephalic structures in trilobites we might consider the relation between the mouth and the surrounding labrum, appendages and postoral plate in order to get some idea of the way of feeding in these primitive arthropods.

As mentioned above most authors have claimed a masticatory function of the cephalic coxa in trilobites. The coxæ have been regarded as acting powerful jaws (Richter 1932, p. 847) just like the mandibles in Crustacea and Insecta. Erikson (1934, p. 254) mentions that no decisive proof of the presence of a gnathobase in trilobites is presented in the published photographs, but since such a structure is demonstrated in Beecher's careful reconstruction he thinks they were evidently present. Erikson points out, however, that the elongate median endobase had to be very long because of the great distance between the rows of appendages. In part I (1938, p. 204) I doubt the presence of the long gnathobase (basendite) and at the same time Snodgrass (1938, p. 110) refers to the trilobites as non-mandibulate arthropods, a view also expressed by me (Størmer 1944, p. 34). More recently Snodgrass (1948, p. 2) points out that the leg bases in trilobites "could have had little use as feeding organs other than perhaps that of stirring up the mud from which the animals obtained their food".

The present material gives further information on the function of the cephalic appendages. Because of the somewhat radial arrangement of the cephalic coxa, the frontal pairs of coxæ probably were situated near the mouth. The coxæ have no elongate gnathobase or basendite developed. The median border of the coxæ is but slightly protruding forming a basendite of the same type as those in the thorax. The median border my have been provided with spines such as the coxæ of the thorax, but there is no unmistakable evidence of a special development of teeth and nodules such as would be expected on the surface of true gnathites. At the same time the cephalic coxæ, just like the thoracic ones, are set well apart making it impossible for the median margins of the coxæ to meet each other along the median line. The structures mentioned make it very probable that the cephalic coxæ in trilobites did not serve as jaws.

In order to comprehend the mode of feeding in trilobites it is useful to compare the trilobite structures with those in other arthropods particularly the Xiphosura. Neither the Xiphosura are true mandibulate arthropods. In the limulids the coxæ are radially arranged round the mouth with the spiny median lobes almost meeting across the mouth. The food, consisting principally of worms and small molluscs, is caught by the pincers of the legs and placed between the coxæ which with their spines push it forward to the mouth. The coxæ are apparently to some extent able to crush the food, but the grinding is carried out in the proventricular gizzard into which the prey is ingested. (comp. Snodgrass 1948, p. 17). Larger, not assimilable pieces of food are gulped up and rejected (Fage 1949, p. 232).

In the Eurypterida the prosomal coxæ might have formed a similar feeding organ. The eurypterid coxæ seem, however, to have been more able to crush the food.

As mentioned above the Arachnida have no indication of jaws. These arthropods live on liquid food only, the food being ingested by means of an efficient sucking pump. As an exception it might be mentioned that the primitive Phalangida (Opiliones) also ingest fragments of their food besides the liquid (Snodgrass 1948, p. 50).

In the Arachnida the prey is brought by the chelicera into a specially developed intercoxal antechamber or preoral cavity.

Judging from the development of the cephalic coxæ, the trilobites were hardly able to crush the food such as is the case in the Xiphosura and evidently even more so in the Eurypterida. Otherwise the feeding organs seem to have been much alike although no trace of a gizzard has been found even in the well preserved trilobite specimens from the Middle Cambrian Burgess Shale.

The strong development of the labrum in trilobites indicates the formation of a preoral cavity bordered laterally by the cephalic coxæ and posteriorly by the postoral plate. In this preoral cavity the food was probably brought in by the legs (telopodites). By means of a sucking organ or pharynx the food might have been ingested and ground in some kind of a gizzard in the frontal portion of the head. As discussed in part I (1939, p. 224—227) the food might have been transported to the preoral cavity not only be means of the legs. The filamentous gills of the appendages might have served as filters holding back the food-particles from the water passing through them. By a certain undulating contraction of the gillbearing appendages the food particles might possibly have been pushed forward to the head region where they might have entered the preoral cavity in front of the coxæ.

We may conclude by stating that the feeding organs of the Trilobita did not include true jaws such as in the Crustacea and the Myriapoda-Insecta. The food, consisting either of softer bodies, or finer food particles embedded in mud or extracted from it by means of filters, was probably brought into the preoral cavity from which it was ingested by means o ofa sucking organ and carried into a more or less developed gizzard lying in the frontal portion of the head. The trilobites seem thus to a large extent to have been mud feeders.

Remarks on the previously described section series of the thoracic appendage in Ceraurus.

In part I (1939) the general structures of the thoracic appendages in trilobites are discussed. From studies on *Ceraurus* in particular, I arrived at the conclusion that the trilobite appendage comprises a precoxa with two branches attached to it: a branchial ramus (preepipodite), and a walking leg (telopodite) with a powerful basal joint forming a coxa.

In a paper not accessible to me until after the war, Garstang (1940) criticises my interpretations of the thoracic structures demonstrated in my section series. He publishes certain drawings based on small-size photographs reproduced in my paper. In order to meet his criticism I have reproduced in stronger magnification (pl. 3, fig. 1—6) certain details of the photographs, and prepared outline drawings of the sections series (text-fig. 8) and of the wax-model prepared from the series (text-fig. 9).

In Garstang's drawings, and also pointed out by him in the text (p. 62), there appears to be a great difference between sec. 39 and 40. As shown in text-fig. 8 this is not the case, but this may have been somewhat difficult to acertain from the photographs reproduced in my paper. Garstang points out that while I claim the diameter of the precoxa to be 1.4 mm, the sections only show 0.8 mm. As shown in the drawings (text-fig. 8) the sections 45, 41 and 40 have a diameter of about 1.2 mm and the figure 1.4 mm was stipulated not from a single section, but from the dimension suggested in the wax model.

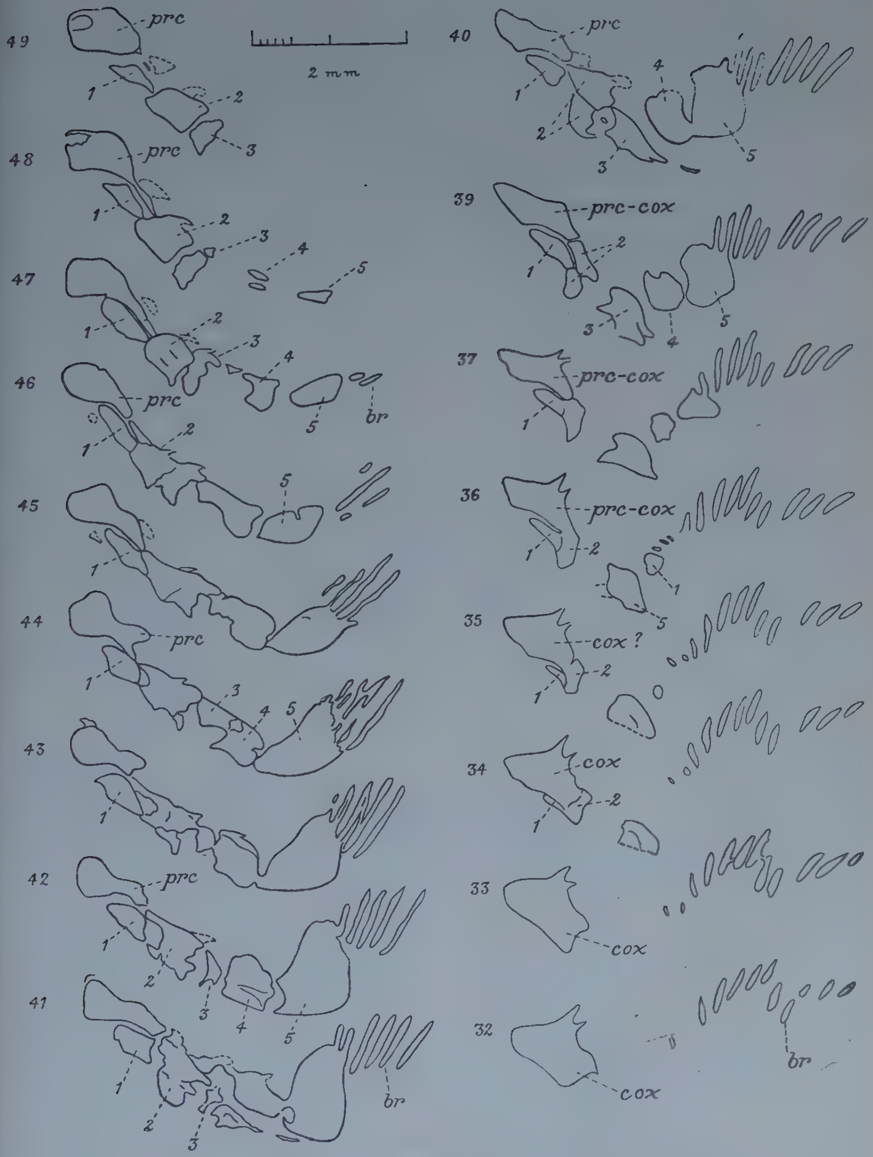
Garstang means to find a discrepancy in my treatment of the sections which in my opinion formed a transition between the presumed precoxa and the coxa. He indicates (p. 63) that in the text I treat the sections 36—39 as coxal, while in the lettering of the sections I draw the limit between coxa and precoxa at a higher level, viz., between 34 and 36. His argument is chiefly based on his assumption that in sections 36—39 the long backwards extension is identical with the postlateral process of the coxa described by me and shown in my wax models and reconstructions. This is not the case. As indicated in the drawing of the model in text-fig. 9, 2 (extended portion marked with an arrow and 39), this backwards extension was regarded by me as part of the branchial ramus, not as part of the coxa. In my description (l. c. p. 198, 181) I said that the postlateral margin of the coxa covered the first joint of the preepipodite (branchial ramus) and the proximal part of the second joint. Garstang evidently misunderstood this expression although the reconstructions (text-fig. 10 and pl. 11) showed that less than half of the second joint is covered by the postlateral process. In the sections 36—39 the backward extension may seem to be composed of two bodies lying side by side as mentioned by Garstang, but a careful study of the photographs might suggest a further division as indicated in text-fig. 8 sec. 39, and pl. 3, fig. 5.

In my description of the precoxal region (36—48) I say: "we notice a distinct line of division between the two elongated segments lying side by side". Garstang finds that this reference, "though not explicit, can only be the two dark strips in the coxal shield of sections 36—39", and therefore is of the opinion that I have called the same thing coxa in one place and precoxa-preepipodite in another connection and thus have no real grounds for my views. To this I want to point out: 1. that Garstangs criticism evidently is based on his erroneuos conception of the postlateral process on the coxa (sec. 39), and 2. when mentioning "two elongated segments lying side by side", I meant, as pointed out in the text, the segments demonstrated in sections 36—48, not only those in sections 36—39. I admit that the expression "lying side by side" might be somewhat inacurate as long as the two segments are actually separated from each other in several sections.

To summarise briefly, my opinion on the basal portion of the appendages was that the subcoxal membrane was limited to the sections below (dorsal) to sec. 49 (?). In the sections following (from 49 to about 36) the two proximal points were interpreted as precoxa and basal segment of the branchial ramus or preepipodite attached to it. The border-line between the precoxa and the overlying (ventral) coxa was not actually demonstrated but indicated by the general shape and direction of the basal portion of the appendage.

Garstang interprets my precoxa (as far up as to section 40—41) as the collapsed subcoxal membrane (l. c. p. 62). The other proximal joint or body is interpreted by him as the basal joint of the branchial ramus, but since my precoxa is interpreted as a subcoxal membrane he has to have the basal segment of the branchial ramus attached to the inner surface of the coxal shield (l. c. p. 64). He points out that the mentioned basal joint of the branchial ramus exactly underlies a part of the coxa.

In the text-fig. 8 it is possible to follow the first joint of the branchial ramus from sec. 49 and upwards (ventrally) through the series. The joint lies close to the precoxa in sec. 47, but is more or less separated from this joint upwards through the series. The first



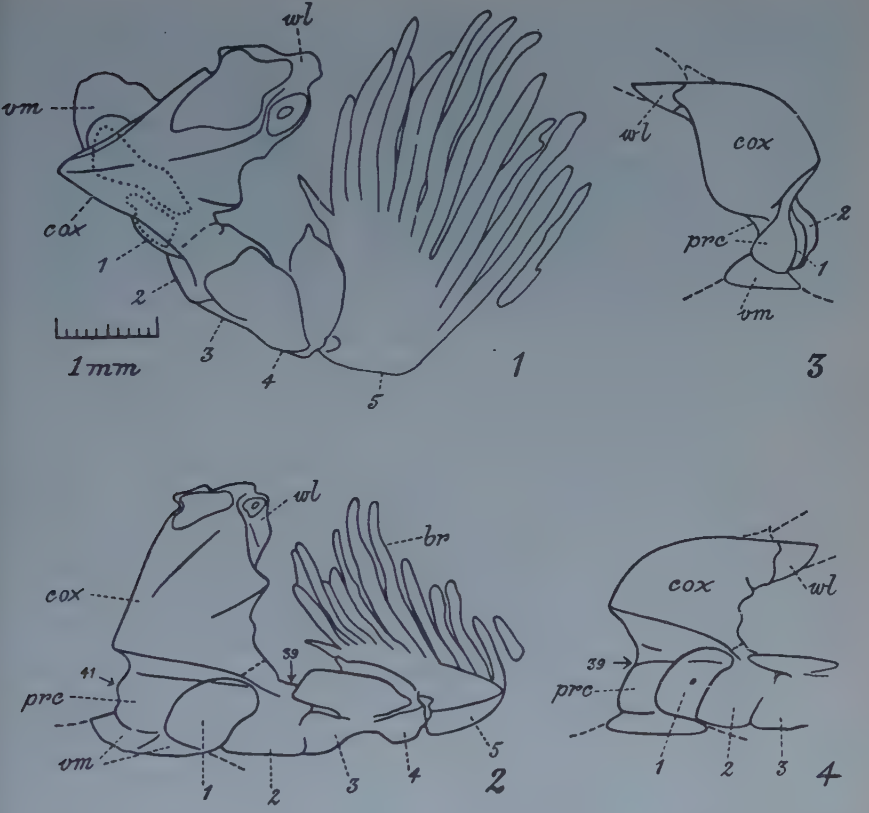
Text-fig. 8. Outline drawings of sections of one thoracic appendage in Ser. C of *Ceraurus pleurexanthemus* Green. Ser. 32—49. *br* = gills, *cox* = coxa, *prc* = precoxa, 1—5 = joints of branchial ramus (preepipodite).

joint of the branchial ramus is easily separable from the precoxa and also from the second joint of the ramus in all sections up to 39. Here the second joint of the branchial ramus seems to be morec losely connected, both with the precoxa and the first joint of the ramus, a fact which led Garstang to the erroneous conception that the whole backwards extension belonged to the coxa. As shown in the text-fig. 8 it seems possible to trace the first joint of the ramus up to sec. 34. The structure is illustrated in the drawings of the wax model (text-fig. 9, c, d). If we follow Garstang's view assuming a collapsed subcoxal membrane up to sections 40—41, only a very small portion of the first segment of the branchial ramus abuts to the coxa. Garstang's definite conclusion that the branchial ramus is an outgrowth from the inner surface of the coxal shield, seems therefore most unlikely.

Garstang's interpretation of one of the basal bodies being a collapsed subcoxal membrane seems also improbable for other reasons. It is hardly likely that of two well-preserved basal bodies, one should represent a collapsed membrane and the other a solid joint. With the assumed height of the membrane (a height which seems to have been the same in appendage II of the same series) no articulation could have taken place between the body and the appendage.

To me it hardly seems doubtful that the branchial ramus was attached to the very basal portion of the appendage, i. e. to the portion interpreted by me as the precoxa. The fact that the basal joint of the branchial ramus and the presumed coxa are separated from each other in many sections does not contradict this explanation. The intersegmental membrane might have been destroyed so that the mud penetrated in between he joints. Concerning the presence of a separate distinct precoxa, it must be admitted that the proximal and distal border lines are not distinctly demonstrated in the section series. It has, however, to be remembered that such a line may not have been distinguishable in sections more or less parallel to the joints. The evidence which led to the assumption of such a joint is the general difference in shape and direction of this joint compared with the coxa (text-fig. 9, 1).

As pointed out above I do not agree with Garstangs criticism and interpretation of the sections. I may admit, however, that some of my expressions might have been more accurate, and with regard

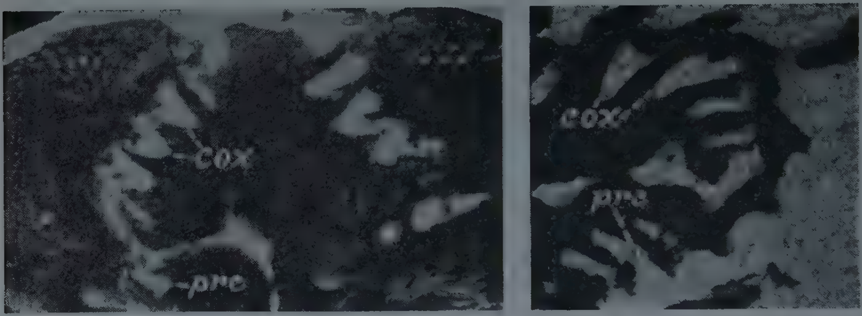


Text-fig. 9. Outline of wax model of thoracic appendage of *Ceraurus pleurexanthemus* Green. The model is based on Ser. C (Størmer 1939). *br* = gills, *cox* = coxa, *prc* = precoxa, *vm* = ventral membrane, *wl* = walking leg (telopodite). 1—5 = joints of branchial ramus (preepipodite), 39, 41 = position of sections.

to the presence of a separate precoxa the opinion expressed by me might have been a somewhat less conclusive.

The section series described in the present paper do not, on account of the incomplete preservation, give any decisive evidence in favour of the presence of a precoxa. A blunt median margin on the basal portion of the appendages in series K, however, suggests structures similar to those described in part I (1939).

One of Walcott's slides (text-fig. 10 a) also shows the blunt median margins of the basal portion of the appendages. The coxæ on the other hand, have an acute median margin. Walcott (1921, p. 397



Text-fig. 10. *a* = *Ceraurus pleurexanthemus* Green. Transverse section of enrolled specimen demonstrating basal portions of appendages. *b* = *Calymene senaria* Conrad. Longitudinal section, showing ventral membrane and basal portion of appendages. *cox* = coxa, *prc* = precoxa. (After Walcott 1921.)

and p. 401) also considered the possibility of a precoxa in *Calymene* and *Ceraurus*. In certain specimens of *Calymene* and *Ceraurus* (text-fig. 10 b) he found suggestions of a small very short joint between the coxopodite and the ventral surface. It deserves to be mentioned, however, that he also ventilated another interpretation suggesting the narrow connection between the coxopodite and the ventral side to be "a cross section of the space occupied by the muscles connecting the ventral integument and the axial processes and mesotergite of the dorsal test". Walcott probably meant a proximal portion surrounded by a subcoxal membrane.

Judging from the structures demonstrated in *Calymene* and *Ceraurus* we arrive at the following conclusions concerning the appendages of these forms:

The biramous appendages have a prominent coxal region. Whether the elongate basal portion of this region represents a separate joint, a precoxa, is not decisively determined as long as the actual jointline is only indicated in one of Walcott's slides. The presence of a separate joint is, however, suggested by the difference in shape and direction of the basal elongate portion in comparison with the typical coxa. The branchial ramus is attached to the basal body (a smal portion seems to abut to the lateral base of the coxal body).

Reconstructions of Ceraurus and Olenoides.

Reconstructions of these genera have been published by Walcott (1918, p. 30 and 1921, pl. 94) and Raymond (1920, text-fig. 8 and pl. 11). Since new informations have been obtained since then, I have found it appropriate to present new reconstructions of the two genera.

In the reconstruction of *Ceraurus* (text-fig. 11) the gills are directed backwards such as demonstrated in *Olenoides* and *Triarthrus*. In fact specimens of *Ceraurus* often show the gills turned forwards (Størmer 1939, text-fig. 8, 9 and text-fig. 3 of the present paper). The position of the gills may therefore have been somewhat different from what is suggested in the reconstruction. The tuberculation of the dorsal test is somewhat schematic. Probably each tubercle was provided with one sensory hair not indicated in the reconstruction. Hairs or setæ were probably also present on the antennæ and other appendages. A lower lip was present, but since it is not actually found, the probable outline is just suggested.

The reconstruction of *Olenoides* (pl. 12) is to a large extent based on Walcott's figures and descriptions. The structure of the gill-branches (Størmer 1933) and the find of a lower lip furnish the new evidence.

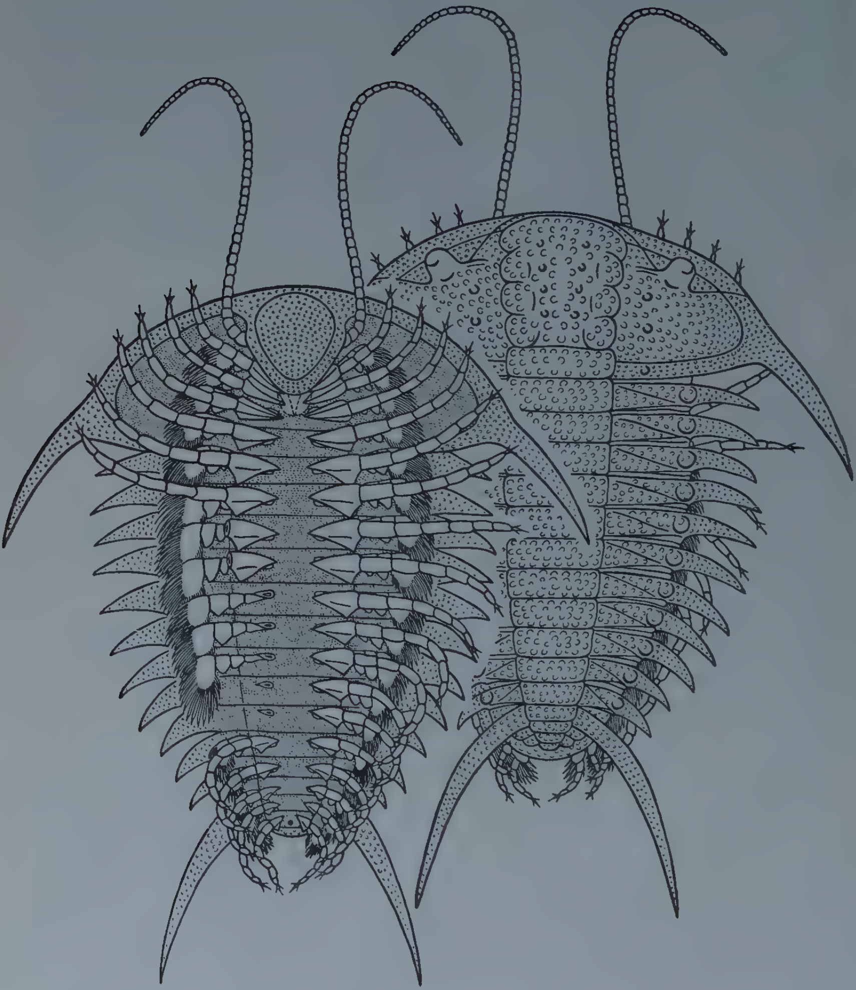
In both reconstructions the ventral integument is dotted.

Interpretations of the coxal region of the trilobite appendage.

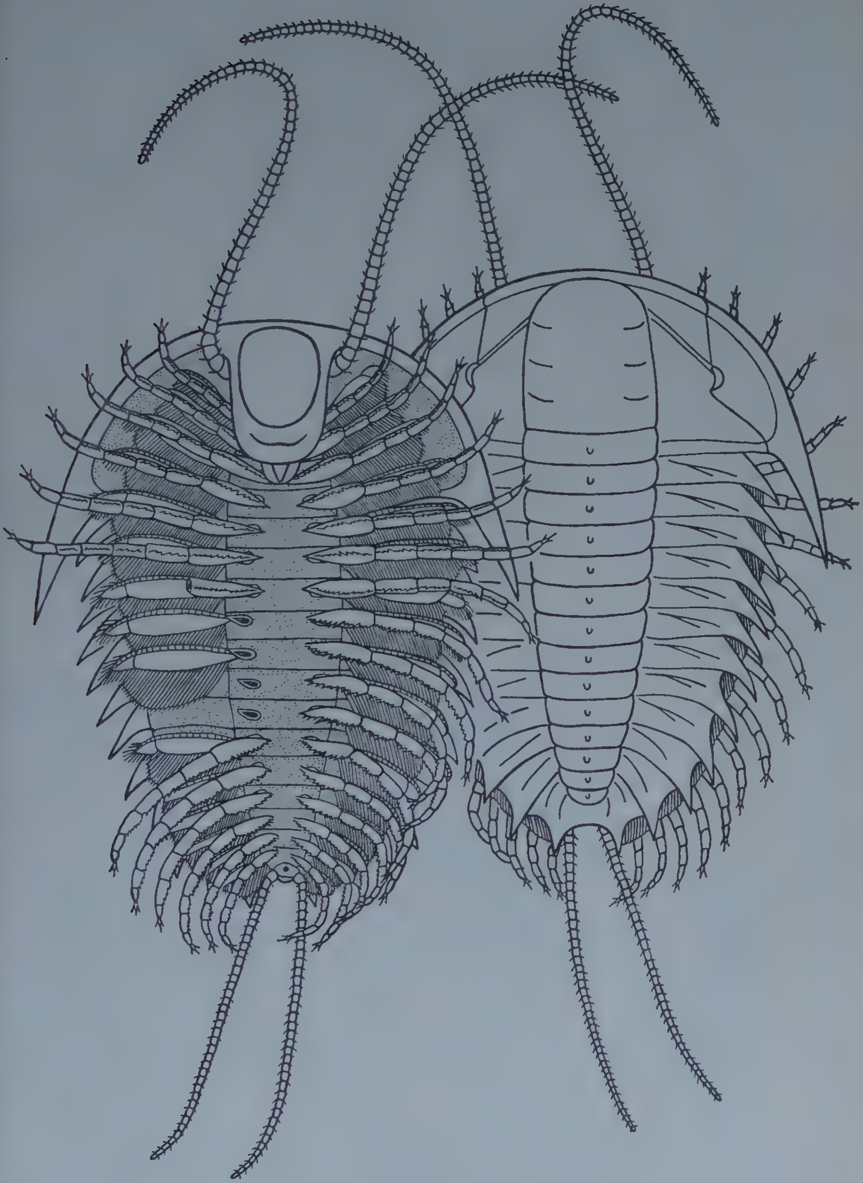
Different opinions have been expressed in connection with the interpretation of the basal structures of the trilobite appendages. Calman (1939) is inclined to regard the short precoxa as a protopodite (sympod or peduncle) with the branchial ramus representing the exopodite. A similar view has more recently been advocated by Heegaard (1945, 1947) and suggested by Vandel (1949, p. 90).

When Calman interprets the basal joint as a protopodite it is apparently because he is convinced that the trilobites are crustaceans and because an unjointed protopodite (peduncle) occurs in not a few crustaceans.

I have previously (1944, p. 121) pointed out that Calman's interpretation meets with considerable difficulties. It involves among others a peculiar rather unique development of the ischiopodite and



Text-fig. 11. Reconstruction of *Ceraurus pleurexanthemus* Green from the Middle Ordovician of U. S. A.



Text-fig. 12. Reconstruction of *Olenoides serratus* (Rominger) from the Middle Cambrian of U. S. A.

necessitates the presence of eight (possibly seven) segments in the endopodite, structure apparently unknown in the Crustacea. I also pointed out that since primitive Crustacea, according to Hansen (1925, 1930) and others, had a sympod of three separate joints, a short undivided protopodite in the very primitive Trilobita was most unlikely.

Heegaard (1945, 1947) has questioned Hansen's conception of a primary three-jointed sympod, a conception which Hansen arrived at from his extensive comparative studies on recent Arthropoda. Heegaard believes the unsegmented sympod to be the primitive structure. The division into three joints is thought to be a secondary formation. He bases his opinion on ontogenetic studies on copepods, parasitic in particular. The crustacean appendage first develops as a bud which becomes bifurcate before any articulation appears. In the nauplius the endo- and exopodites contain several joints while the sympod is still undivided. According to Heegaard the division of the sympod appears later in the ontogeny and is therefore believed by him to be a secondary formation. As an example of this he mentions the late appearance of a middle joint in the sympod of *Calanus tonsus* (Campbell 1934).

But does this ontogentic development give any real clue to the phylogenetic development? When Heegaard puts such weight on the lack of separate joints in the sympod of the ontogenetic stages I think he is carrying the biogenetic law a little too far. Even if the primitive arthropods had a threejointed sympod one would hardly expect to find the early, imperfectly developed bifurcate appendage in later forms divided into a complete number of segments. Lang (1946, 1948) strongly criticises Heegaard's conclusions which he finds not well founded. Lang mentions (1946, p. 8) that although he at first was very sceptically inclined towards Hansen's theory on the three-jointed sympods, he afterwards changed his mind: "I was, therefore, very astonished after an extremely careful examination of the extremities of the harpacticides, to find myself convinced that Hansen is right after all".

Only the fossil material is able to decide whether or not the larger number of joints in the appendage is the primitive character. Unfortunately the fossil record on early primitive crustaceans is rather incomplete as far as the appendages are concerned. It might be mentioned that in the Middle Devonian *Lepidocaris rhyniensis* (Scourfield 1926) the sympod of the second antenna (I) is divided into 3 distint joints, the precoxa, coxa and basis (basipodite). This division is even indicated in the small larva (text-fig. 14), although the separation of the two basal joints is not quite distinct (Scourfield 1940). This one case is not conclusive, but it shows at least that a three-jointed sympod occurs already in early and apparently primitive crustaceans.

Among the Chelicerata we are more able to follow the development of the joints in fossil and recent forms. In earlier papers (Størmer 1936, 1939, 1944) I have pointed out the presence of a larger number of joints in the appendages of early and primitive members of the Chelicerata. This has been emphasized also by Vachon (1944-45, 1945). He points to the fact that in the Lower Devonian *Weinbergina* (Richter and Richter 1929), a primitive Xiphosuran (Synziphosura), the five prosomal legs (II—VI) appears to have a larger number of joints than the same legs in the recent *Xiphosura (Limulus).* In *Weinbergina* all the prosomal legs appear to have the same number of joints as the last pair (VI) in *Xiphosura.* In the four frontal legs of the recent form the number of joints is reduced both in the larva and the adult. Since the more primitive Xiphosura evidently had more joints in these appendages it is hardly doubtful that a reduction in the number has taken pace. This impairs in my opinion Heegaard's arguments against a primary three-jointed sympod in the Crustacea.

Vachon explains the reduction of joints as a case of partial neoteny or merostasis (1945, p. 175). The division into several joints was postponed or never acomplished. The same view might be applied on the conditions in the Crustacea. The late appearance of the division of the sympod or protopodite into two or three joints might be explained as due to partial neoteny rather than signifying a one-jointed sympod in primitive forms such as advocated by Heegaard. The fossil record seems to support Hansen's conception of a reduction rather than an increase in the number of joints in the arthropod appendage during the phylogenetic development.

It thus appears to be but slight evidence in favour of interpreting the short basal portion of the trilobite appendage as a protopodite or sympod.

We shall now consider my arachnomorph interpretation of the trilobite appendage (Størmer 1939, 1944).

Among the Chelicerata Vachon finds it possible to refer the joints of the appendages to four primary groups: the protocoxa, protofemur, prototibia and prototarsus. The fossil arachnids show more joints than the related recent ones. In its complete development the appendage is supposed by him to have had 9 joints composed of 3 + 2 + 2 + 2 joints. The trilobite appendage (in my interpretation) would according to Vachon just demonstrate the primitive chelicerate appendage such as it would be expected.

The interpretation of the trilobite appendage as composed of a precoxa, coxa and a seven-jointed walking leg finds its chief support in the identification of the coxa. A prominent coxa similar to that in trilobites, is found in the Xiphosura which have so many other characteristics in common with the Trilobita.

The interpretation of the powerful plough-shaped joint in the trilobite appendage as a coxa involves the identification of the basal joint as a precoxa (or possibly as a basal portion of the coxa) and the branchial ramus attached to it as a preepipodite (or possibly an epipodite).

Among the Chelicerata a precoxa is not at all a common structure and its presence is not unanimously accepted. The presence of a precoxa in the five posterior prosomal appendages (II—VI) of the Xiphosura is suggested by Coutière (1919), Størmer (1939, 1944) and Fage (1949). The muscles of the joints present, however, no evidence for or against this assumption which is based on certain lines on the test (Vachon 1945, p. 292). (Another in my opinion less probable interpretation of the coxal region in *Xiphosura* has been suggested by Heegaard 1947, p. 184—185).

An unjointed appendage, the flabellum, is attached to the lateral, possibly precoxal, portion of the coxal region. In the Japanese xiphosuran *Taclypleus tridentatus* the lay outs of such appendages are found also on the other prosomal legs. It seems natural to homologize these organs with the branchial ramus of the trilobites (Størmer, 1939). In the abdomen of the Xiphosura a prominent gillbranch similar to that in trilobites, is present and it is of importance to notice that it is attached to the very base of the appendage just as in trilobites.

In the Arachnida a rudimentary precoxa has been demonstrated in the Acarina by Schulze (1932) and by Ruser (1933). Neumann (1941, p. 619) shows, by the attachment and course of the muscles, that the basal portion of the syncoxa represents a real precoxa. The same author (1942) has also meant to trace rudiments of a precoxa or corresponding muscles in primitive arachnids such as the Solifugae, Araneae and Pseudoscorpionidea.

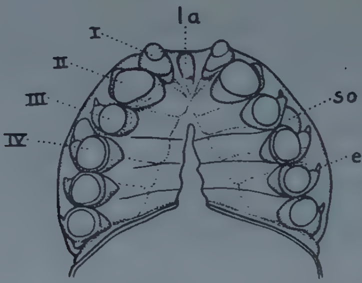
In part I (1939, p. 249) I suggest the possibility that a certain organ, the cymatium, in the syncoxa of the Acarina may be interpreted as a rudiment of a preepipodite of the type found in the trilobites.

Certain lateral sterno-coxal processes in the embryo of *Euscorpius* are regarded by Dawydoff (1949, p. 348) as without doubt homologous with the flabellum on the sixth prosomal appendage of *Xiphosura (Limulus)*. Median processes in the prosomal appendages of the embryo of Araneae have been interpreted in the same way, but I find it more probable that these processes are rudimentary coxal endites such as explained by Schimkewitsch who originally described them (Schimkewitsch 1911, p. 691—692, pl. 1, fig. 28).

Ecdysial teeth are a common feature in the embryo of the Arachnida. The teeth serve to puncture the cuticle during the ecdysis. In the primitive Pedipalpi Kästner (1949) has demonstrated the ontogenetic development of the organ. Already in an early ontogenetic stage (text-fig. 6) a small bud (*et*) on the lateral basal portion of the pedipalps (II) indicates the ecdysial tooth. In a later stage (text-fig. 13) the lateral processes forming the ecdysial teeth are very distinct. In this stage the shape and position of the coxæ in relation to the mouth are much more trilobite-like than in later stages where the coxæ form larger plates meeting along the median line. The general appearance and position of the ecdysial teeth in the Pedipalpi might suggest these organs to be remnants of the lateral branch (preepipodite) in the appendages of the Trilobitomorpha. Other ecdysial teeth may, however, have had an other origin.

As pointed out in earlier papers (Størmer 1939, 1944) the walking leg (telopodite) of the trilobite appendage corresponds well with the legs of primitive Chelicerata.

In general we may state that the appendages of the Trilobitomorpha on one side and the appendages of the Chelicerata on the other side demonstrate so many common features that it seems very probable that the latter type is derived from the former.



Text-fig. 13. Ventral structures of the prosoma in the embryo of *Thelyphonus caudatus* (Arachnida, Pedipalpi). Only the basal portions of the appendages indicated. *la* = labrum, *et* = ecdysial tooth, *so* = sensory organ, *I—IV* = primarily postoral appendages. (After Kästner 1949.)

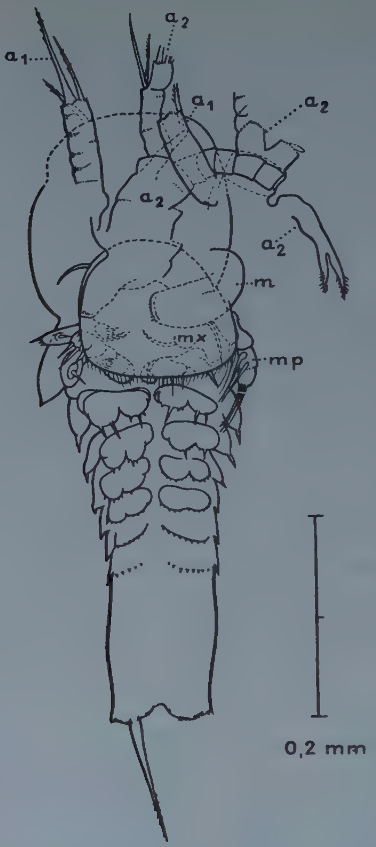
Remnants of the characteristic trilobitan appendage are recognized in many different groups of the Chelicerata. The remnants are preserved also in terrestrial forms having a mode life very different from the marine trilobites.

It is possible also to trace a distinct connection between the trilobitan and crustacean appendage? As mentioned above some recent authors such as Garstang and Gurney (1938), Calman (1939, Garstang (1940) and Heegaard (1945, 1947) have interpreted the trilobitan appendage as homologous with the appendage of the Crustacea. An essential feature in the crustacean appendage is the bifurcation, the two branches (the endopodite and exopodite) attached to a basal sympodite or protopodite. The bifurcation also of the trilobitan appendage is taken as a strong suggestion of homology of the two types of appendages. The trilobitan "exopodite" is attached to the very base of the appendage and differs in this respect from the crustacean exopodite which is attached to the distal end of a sympodite. The sympodite may be short and consisting of one joint only, but yet the attachment of the exopodite is different. The "exopodite" of the Trilobitomorpha is normally provided with gills, an organ which in the crustacean appendage is connected with the preepipodite and epipodite, not the exopodite.

Of course a transition from the trilobitan to the crustacean type of appendage may theoretically have taken place. It was assumed by Raymond (1935) and by the more recent authors cited above. The "crustacean" interpretation of the trilobite appendage meets, however, with certain difficulties (p. 141). Since the gillbranch is attached to the very base of the appendage, this portion has to be interpreted as the sympodite or protopodite, an explanation which involves the presence of eight or at least seven joints in the "endopodite" (seven joints if the coxa is regarded as belonging to the same joint as the basal one). This number exceeds the five to six joints in the crustacean endopodite (Størmer 1944, p. 121).

In spite of the difficulties the possibility of a transition from the trilobitan to the crustacean appendage may not be excluded. But why do we not find any distinct signs of such transition? The trilobitan appendage is traced among numbers of the Chelicerata, particularly in the aquatic ones, but apparently also in forms having attained a terrestrial mode of life. My previous studies (1939) have shown the trilobitan appendage to be a very conservative structure which is maintained in very different form of Middle Cambrian Trilobitomorpha, forms belonging both to the benthos, necton and plankton. It might be objected that some of the mentioned Middle Cambrian arthropods in fact were crustacean, but even if this should turn out to be the case, it is difficult to understand why no existing crustacean shows distinct traces of the trilobitan appendage. As mentioned above the Middle Devonian *Lepidocaris* (text-fig. 14) has typical crustacean legs. Garstang and Gurneys (1938) and Garstang (1940) explain the elongate sympodite in the Crustacea as being formed when the appendage developed from a less movable appendage confined to the sub-pleural chamber, into a free swimming organ. This development has not been demonstrated in the fossil record and it might be mentioned that nor are any signs of elongate sympodites found in Middle Cambrian Trilobitomorpha with more or less freely exposed appendages (Størmer 1939, p. 239). The mentioned authors also state that the pleural "scales" which overlap the bases of the appendages in *Lepidocaris* on one side are clearly foreruners of the pre-epipodites (proepipodites) of the Anostraca and on the other side no less clearly homologous with the pleura of Trilobites. If we consider homologies of this, in my opinion rather far-fetched type, any transition may be possible. It seems, however, more safe to confine ourselves to the observed facts.

With our present knowledge it seems to me less probable, though not impossible, that the crustacean appendage evolved from the appendage of trilobitomorph ancestors.



Text-fig. 14. Early larva of *Lepidocaris rhyniensis* Scourfield from the Middle Devonian Rhynie Chert, Scotland. Ventral view. a_1 = first antenna (antennule), a_2 = second antenna (antenna), m = mandible, mx = maxilla, mp = maxilliped. (After Scourfield 1940)

The zoological position of trilobites.

In part I (1939, p. 147—152) I give a brief review of the various conceptions of the zoological position of the trilobites. It appears that the opinions have changed considerably from time to time. Referring to my previous review of the literature, I am in the present connection dealing only with the more recent literature.

In my paper on the Arachnomorpha (1944) I have treated the problem on the probable relationship between the Trilobita, Chelicerata and other groups of Arthropoda. I arrived at the conclusion that the

Trilobita and the Chelicerata and certain other extinct arthropods were mutually related forming one larger taxonomic unit for which I adopted the name Arachnomorpha, a name primarily introduced by Heider. The forms provided with preoral antennæ and trilobitan appendages were included in the new subphylum Trilobitomorpha corresponding in rank to the Chelicerata characterized by the lack of antennæ and the presence of chelicera.

I found it less probable that the Crustacea were derived from the Trilobitomorpha, but could on the other hand not definitely exclude the possibility of a relationship (p. 143).

As characteristic of the Arachnomorpha I pointed out (p. 128):

1. The trilobation of the dorsal shield, the presence of a well-defined headshield, and the tendency to develop a styliform telson.
2. The presence of 4 postoral larval or primary somites.
3. The appendages of the postoral somites being either trilobitan limbs or modifications of this type of appendages.
4. The intestinal diverticulæ being very strongly developed.

Within one large taxonomic group, comprising many different genera, it is of course difficult to demonstrate particular characters which are present in all genera and at the same time confined to this one group only. In many cases the significant characters may be traced to a small extent also in other groups, and it is more or less a matter of judgement to which degree this occurrence means affinities or merely coincidence. Although the trilobation is found in other groups it is rather characteristic of the Arachnomorpha.

Heegaard (1945, p. 10) and Linder (1945, p. 22) question the importance of the trilobation in the Trilobitomorpha and the Chelicerata. Heegaard explains it as "being mainly based on biology", and Linder points out that the trilobation among the Crustacea is not confined to members of the Isopoda ond Decapoda, but occurs also in the Branchiopoda.

The value of the four postoral larval or primary somites has also been discussed. Their presence in the Trilobita and the Xiphosura seems to indicate a relationship between these groups, but since we do not know for certain whether the crustaceans have two or four larval somites, this character cannot be used as a decisive character separating the Arachnomorpha and the Crustacea.

Linder (1945, p. 21) points out that among the Crustacea strongly developed intestinal diverticulæ are not confined to a few parasitic copepods only, but are characteristic also of the head of most branchiopods. This impairs somewhat the importance of the intestinal diverticulæ as significant characters of the Chelicerata such as urged by Kästner (1940) and maintained by me.

Tiegs (1947, p. 318) discusses the relationship between the different groups of the Arthropoda. He is inclined to regard the affinities between Trilobita and Arachnida as closer than with the Crustacea and finds that the primitive fossil Xiphosura shows a most remarkable resemblance to trilobites. (The articulated telson spine is thought to form an exception, but as I have previously pointed out (Størmer 1944, p. 115) Ivanov's (1933) studies on the ontogeny of *Limulus (Xiphosura)* rather supports the resemblance). Tiegs assumes that both the Chelicerata and the Crustacea evolved from the trilobite stem.

The affinities of trilobites are discussed recently in Volume VI of Traité de Zoologie edited by P. P. Grasse (Vandel 1949, Waterlot 1949, Fage 1949 and Størmer 1949).

In his general review of the Arthropoda (Vandel 1949, p. 147) arrives at the conclusion that the Trilobita cannot be placed in any of the recent classes of the Arthropoda. The Trilobita are regarded as a very primitive group which Vandel prefers to place in a separate subphylum for which he proposes the name Proarthropoda. Following Heegaard and others before him he figures the trilobites to be closely related to a presumed common ancestor of both the Chelicerata and the Crustacea. He is not inclined to attach much importance to the trilobation, the number of primary somites or the non-crustacean interpretation of the trilobitan appendage. At the same time (l. c. p. 146) he is primarily disinclined to place the Trilobita and Chelicerata in one taxonomic group as long as the former have antennæ and labrum and lack the chelicera characteristic of the latter group. The value of these arguments are discussed below, but in this place I want to point out the labrum is not alien to the Chelicerata. A narrow labrum is distinct in the Xiphosura and a labrum is also found in the larval stages of the Arachnida. In the adult arachnids the organ is surpressed in connection with the special development of the preoral cavity.

In his treatment of the Merostomata Fage (1949, p. 246—247) strongly stresses the close affinities of the Trilobita and Xiphosura (in spite of the lack of the antennæ in the latter). He writes: "En realité les rapport qui unissent les Trilobites et les Xiphosures sont si etroites qu'il existe toute une serie de formes que l'on hesite a' classer ici ou la'."

Waterlot (1949, p. 215) emphasizes the relationship between the Trilobita and the peculiar giant arthropod *Arthropleura* from the Carboniferous.

In my article on the Trilobita (Størmer 1949, p. 186; 187) I give a brief review of the different opinions on the systematic position of the group.

We have now considered the more recent evidence and views on the affinities of the trilobites. It has become apparent that certain features, such as the number of the primary or larval somites, are yet too little known to be able to give decisive evidence. Future ontogeneic studies in particular, may solve or at least throw new light on these important question.

The general phylogenetic and taxonomic problems to be considered may be summarized in two points: 1. Are the Trilobitomorpha related to the Chelicerata? 2. Are the Trilobitomorpha related both to the Chelicerata and the Crustacea, thus being more or less ancestral to both groups?

Concerning the affinities between the Trilobitomorpha and the Chelicerata, recent research seems to confirm the existence of a closer relationship between these groups. Most recent authors seem to have adopted this view. Among the characters common to most members of the two groups may be mentioned:

1. A distinct trilobation representing a strong development of the pleural area of the dorsal shield, a distinct head-shield or prosoma, and the tendency to develop a styliform telson.
2. The lack of true jaws.
3. The postoral appendages being either trilobitan limbs or modifications of this type of appendages.

In addition to these we may mention two extra points which are characteristic of both groups, but which at the same time may possibly be more or less characteristic also of members of other groups e. g. the Crustacea:

4. The presence of four postoral larval or primary somites.
5. A strong development of the intestinal diverticulæ.

With our present knowledge of fossil and recent forms it is considerably more difficult to answer the question whether or not the trilobites also are related to the Crustacea. It is tempting to regard the primitive trilobites as being closely related to the ancestor of both the Chelicerata and the Crustacea. But do we have enough evidence in favour of such a relationship? As I have previously pointed out (Størmer 1944, p. 144) certain Middle Cambrian Trilobitomorpha are very crustacean-like and have in fact been looked upon as true crustaceans by most authors. If the crustacean-like features of these forms are true crustacean characters and not merely matters of convergence, these arthropods must be regarded as transition forms demonstrating direct affinities between the Trilobitomorpha and the Crustacea.

When I doubt the relationship between the Trilobitomorpha and the Crustacea it is chiefly because of the difference in the structure of the postoral appendages. In a previous chapter I have paid attention to the fact that satisfactory transition stages between the trilobitan and crustacean appendages have not been demonstrated as far as I can make out. Traces of the characteristic trilobitan appendages ought in my opinion to have been found in the many types of fossil and recent crustacean appendages. The lack of true jaws in the trilobitomorpha may not exclude the possibility of a relationship between the trilobites and crustaceans, but also here we might have expected to find certain distinct transition stages in the larval or adult stages of fossil or recent forms. In my paper from 1944 I proposed, like did Heider, to include the Trilobitomorpha and the Chelicerata into one phylum the Arachnomorpha, thereby suggesting that the Trilobita were not phylogenetically connected with the Crustacea. Although I am still inclined to hold this view, more recent contributions from zoologists in particular, have shown that a definite decision of the problem is still somewhat premature.

The conclusions to be drawn from the present discussion might be summarized as follows: Recent research indicates the relationship between the Trilobitomorpha and the Chelicerata. The Chelicerata evidently evolved from ancestors not much different from the Trilobita. It still remains an open question, however, whether the Crustacea evolved from the same ancestors and thus also are more closely related to the Trilobita.

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Explanation of Plates.

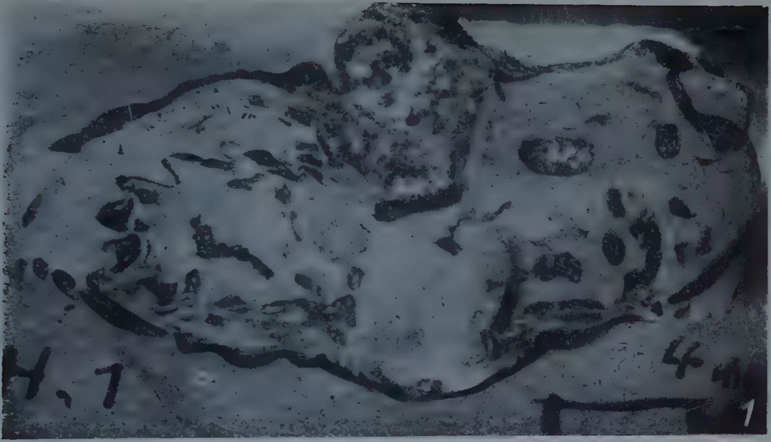
Ceraurus pleurexanthemus Green from the Middle Ordovician Trenton Limestone, Trenton Falls, New York State, U. S. A.; Wallcott's collection. Photographs not retouched.

Pl. 1. Samples of section series H, 5 ×, (comp. pl. 2).

Pl. 2. Wax model of ser. H. Fig. 1 = dorsal view of cephalon, fig. 2 = anterio-ventral view, fig. 3 = ventral view and fig. 4 = posterior view. *a* = antenna, *br* = gills of branchial ramus, *eye* = eye, *cox* = coxa, *gl* = glabella, *glf* = glabellar furrow, *lab* = labrum, *prpd* = branchial ramus (preepipodite), *I—IV* = postoral cephalic appendages.

Pl. 3. Figs. 1—6 = details of ser. C, Nos. 34—37, 39—40 (comp. text-fig. 8).
Fig. 7 = Wax model of ser. K. Ventral view of posterior portion of cephalon and anterior portion of thorax.
Fig 8 = Sample of section series J (comp. pl. 4).
Fig. 9 = Sample of section series K (comp. fig. 7). *br* = gills, *eye* = eye, *gl* = glabella, *prc* = precoxa, *th* = thorax, *I—IV* = postoral cephalic appendages.

Pl. 4. Wax model of ser. J. Dorsal (1) and ventral (2) view of cephalon with two thoracic tergites.. *eye* = eye, *g* = glabella, *gf* = glabellar furrow, *gsp* = genal spine, th_1, th_2 = thoracic tergites, *I—IV* = postoral cephalic appendages.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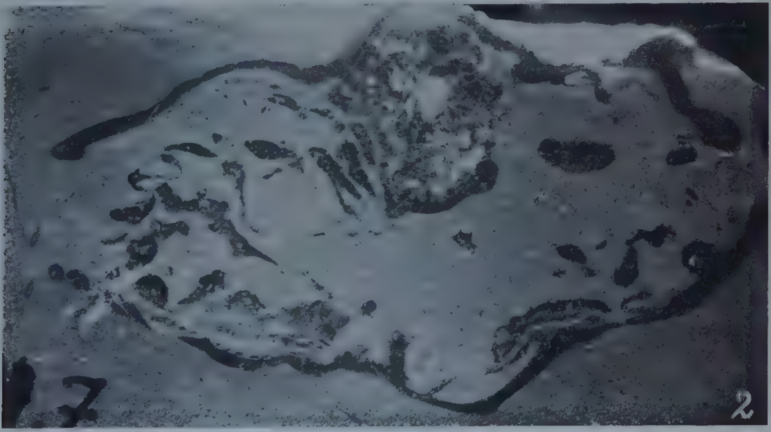
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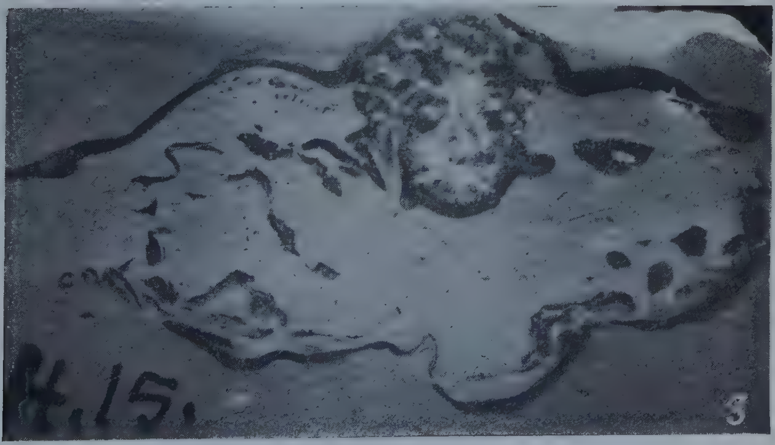
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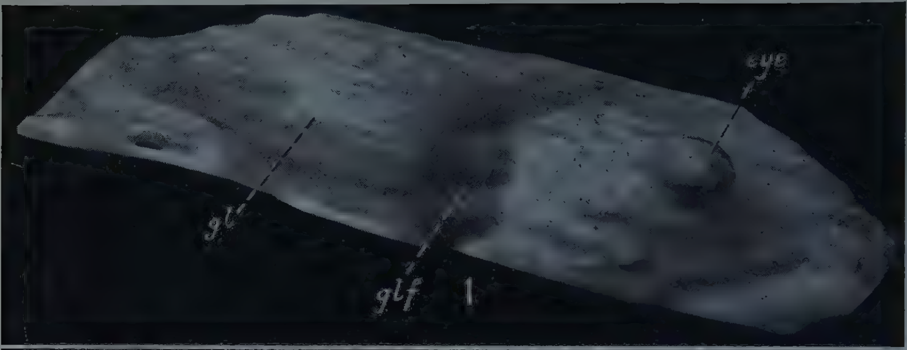
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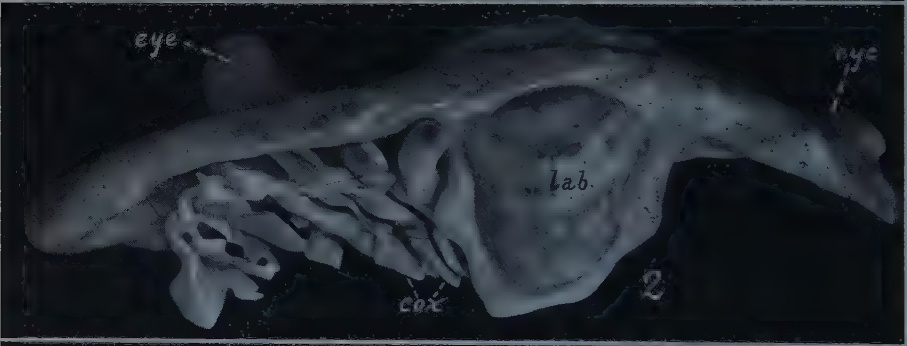
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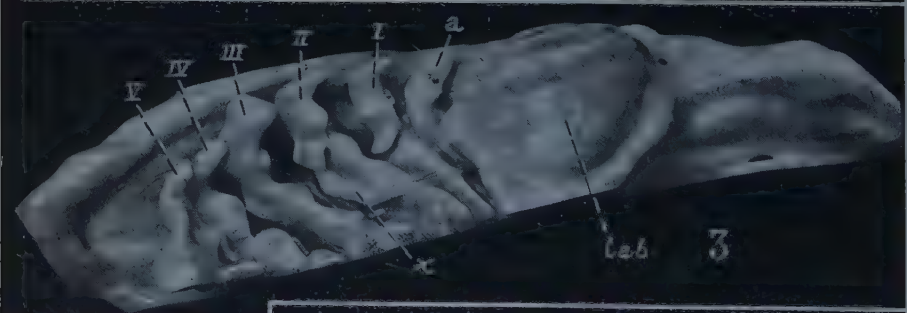
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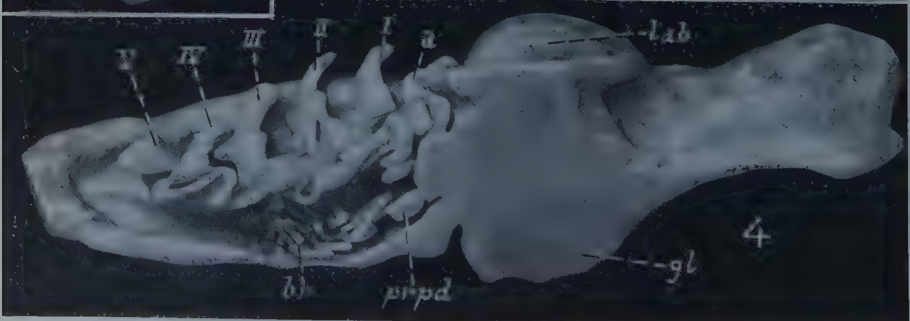
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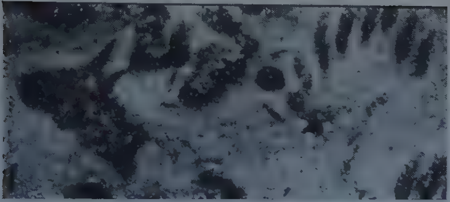
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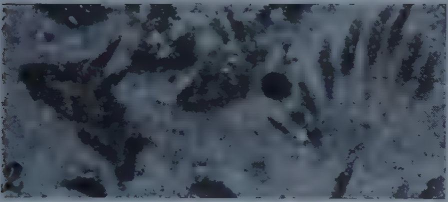
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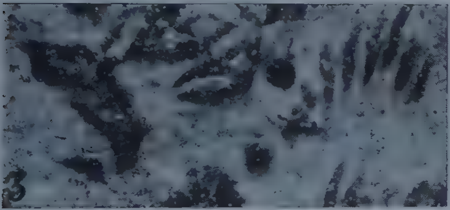
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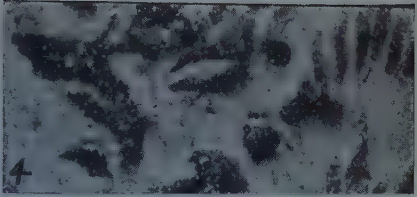
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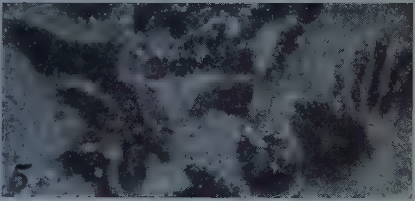
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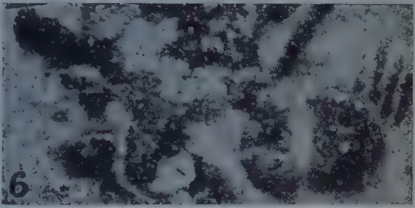
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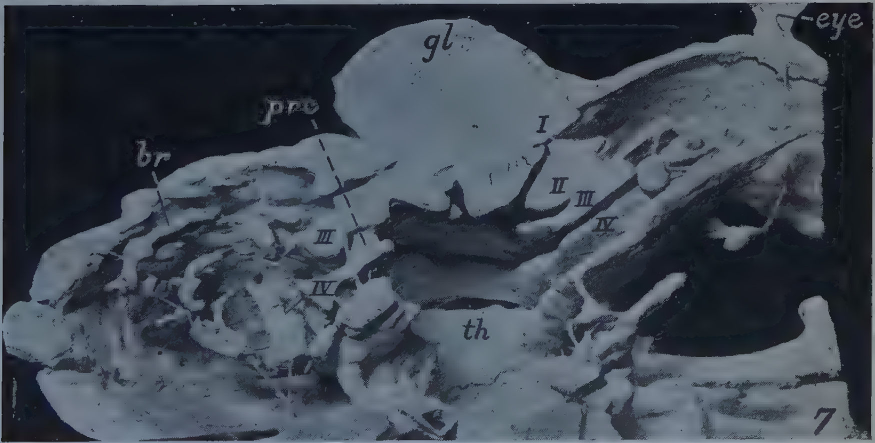

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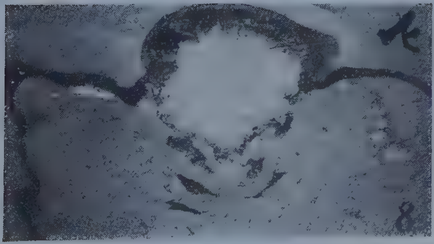
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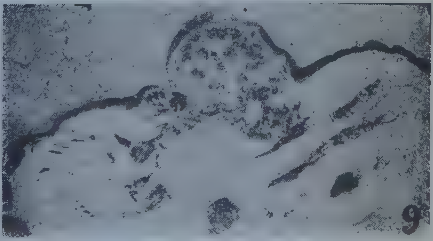
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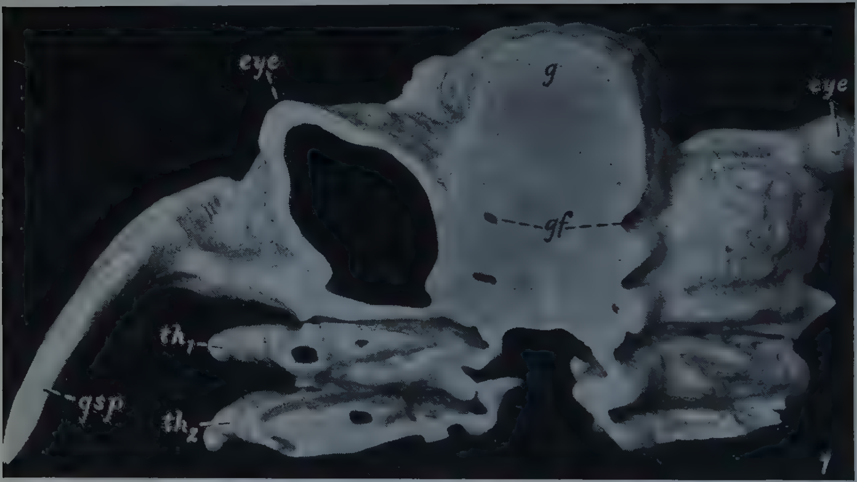

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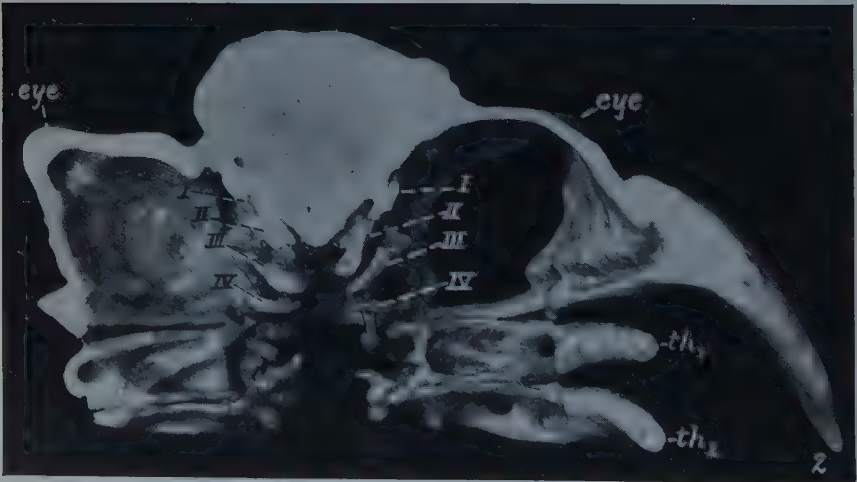

2.

NOTES ON THE ICE-SHED AND ICE-TRANSPORT IN EASTERN NORWAY

BY

Per Holmsen

Abstract: This paper is a short introduction to the essential problems connected with the ice-transported material near the former ice-shed. Observations on scattered erratics and the results of some block-calculations (not the calculations themselves) are communicated. This theme has not, however, been the main object of the field investigations. The author emphasizes the importance of classifying the observations made as to the kind of superficial deposits, viz.: Ground moraine, glacifluvial deposits, and ablation moraine. In this way it seems possible to point out not only the position of the ice-shed during the latest stage of active glaciation, but even traces of an earlier period, the ice-shed having at that time had a position farther to the S than the last one.

Geological field-work during many years in the sparagmite area of eastern Norway has given me the opportunity of studying the erratics, and the following question arose: from where do they come?

As early as in 1854, Hørbye touched on the same question. O. E. Schiøtz' publications (1892 and 1895 a, b) deals with ice-transported boulders. Later on (1914) the same author mentioned the apparently opposite transport-directions of erratics in the district of the Femunden lake. It seemed to him that the erratics west of a line Sorkvola-Tufsingdalen were transported to the south, the erratics east of that line being transported to the north. He attempted to explain these contradictions by assuming the existence of two isolated ice-sheds, 80 km apart. The movement of the erratics was explained as the resulting movement of the ice from these two ice-sheds. His theory is illustrated by fig. 1.

It is not necessary to resort to such a complicated hypothesis in order to explain the transport of the erratics. As emphasized in several publications by A. M. Hansen (a. o. 1895), the ice-shed moved from the water-shed to a SE position during the glaciation period, the rest of the ice finally being situated somewhere far SE of the water-shed, causing the formation of ice-dammed lakes. (See fig. 3.) Apparently, the movement of the ice-shed itself caused differences in the transport at different stages of the glaciation.

My studies on this subject are at a preliminary stage. However, I have made some observations on transported boulders which, I think, throw some light upon this problem.

In the matter of boulder-transport it soon appeared necessary to distinguish sharply between the following three different kinds of moraine depoosits: 1. The ground moraine. 2. The glacifluvial deposits. 3. The ablation moraine. Occasionally, this may prove difficult, but it may in some cases be accomplished by calculating the quantitative boulder composition. The fact is that each kind has its own characteristics, and a short description should therefore be warranted.

1. The ground moraine.

The material is compacted and unstratified, boulders are angular or subangular. A considerable part of these originate from the neighbouring solid rocks, the boulders being mostly sharp-edged. I consider them as having been broken loose and carried away by the ice during the latest glaciation stage. The area in question lies near the former ice-shed. Consequently, they must have been transported only for a short distance, in the direction of the last ice-movement. This part of the boulder material I consider the most important one.

The ground moraine extends nearly all over the area.

2. The glacifluvial deposits.

These deposits are well stratified and sorted according to grain size. Layers of coarse-grained material sometimes intercalates with layers of fine-grained material. The coarse-grained material is always polygenous, and boulders and pebbles are well rounded, only a small percentage of them originating from the neighbouring rock floor. The greater part of the coarser material is doubtful as to origin, but some of it may be identified exactly. This small part of the material offers, however, very interesting features.

The composition of the boulder material indicates a long and complicated history of transport.

The glacifluvial deposits, usually of great thickness, occur at the bottom and on the slopes of the valleys of Eastern Norway. The ground moraine is extensively covered by them.

3. The ablation moraine.

This term comprises the unassorted material of supra- or englacial origin resting upon the stratified deposits mentioned, or directly upon the ground moraine. Except where it is seen to cover the stratified deposits, the ablation moraine is not easily recognized, the boulder material showing few characteristic features as to petrography. The form of the boulders are mostly "ice-moulded". Sometimes large blocks are found, coming from afar, the sources of which may in some cases be traced. These are the true erratics, described by Hørbye, Schiøtz, and Törnebohm.

The ablation moraine, forming the surface-layer of the quaternary deposits in central and eastern Norway, represents the material lying on the surface of and within the dead ice-masses during the melting-down period. Its situation in some cases on well-stratified sand, gravel, and silt, indicates a subglacial origin of parts of the glacifluvial deposits.

The ablation moraine covers the wide, peneplanic areas between the valleys that are a characteristic topographical feature of the greater part of Norway. In the valleys, however, the ablation moraine is often absent. Here the material may have been washed away by melt-water rivers and deposited in a stratified manner, later indistinguishable from the subglacial deposits.

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By interpreting the boulder material as to origin, a thorough knowledge of the rock ground of the total area is essential. In eastern Norway I have succeeded in identifying a few boulder-types in respect of the places from which they have been transported, all possible mistakes being taken into account. Some details are mentioned below.

By studying the sharp-edged boulders in the ground moraine it might be possible to determine the position of the ice-shed during the last stage of active glaciation. It is necessary to search out characteristic rock types having small field extension.

Within a small area in the Øversjødalen valley there are some tillite outcrops as well as a small occurrence of precambrian granite (N. G. U. nr. 158, and 175). Blocks of these rock types have been transported to the NW only, and are to be found in the ground moraine and ablation moraine in this direction. According to this observation the ice-shed (the movement shed) was situated to the S or SE, but a closer determination of the exact position cannot be carried out because of the absence of rock outcrops.

By Ottnes in the Rendalen valley a coarse-grained anorthosite pegmatite occurs, and a similar rock is found some km to the S in the same valley. From these two small and very characteristic occurrences the sharp-edged blocks *of the ground moraine* have been transported to the south only. The same direction of transport is found by a dolerite mass S of the Ottåen river, just W of Ottnes: in a ravine N of the stream, and merely a few hundred meters from the dolerite mass, not a single dolerite boulder is found. To the south, however, a number of boulders of this rock type is scattered southward to Åkre, and even farther a number of single boulders are found on the Storsjøen lake-shore. From these observations I conclude that the ice-shed was situated N of Ottnes.

Tillite occurs near Finstad in the Brydalen valley (the N part of Rendalen), but as yet no observations have been made as to the block transport. W of this place, however, is a precambrian granite and dolerite "window", and from a local outcrop of coarse-grained Åsby-dolerite a number of angular blocks are distributed over the NW arc. Just S of this place the precambrian rocks are overlain by the eocambrian tillite, and boulders from this locality are transported to the NW. Nevertheless, a few granite and dolerite blocks are also found SE of the tillite border line. Boulders of these types are even wide-spread S to Rendalen, and are known as a slight admixture to the glacial and glacifluvial deposits here. These observations seem contradictory, but may be explained by the fact that during the glaciation period, the ice-shed itself moved from the watershed to a SE position. During the first stage the *transport* took a SE direction, while later on the movement reversed. We do not know whether the movement of the *ice-shed* was steady or oscillating, but from the observations in the area W of Finstad I presume that the ice-shed in its last stage was situated SE of Neka, a side-river joining the Rendalen water system.

Further investigations into this matter are to be carried out. Based upon our knowledge so far, however, we may roughly localize the southernmost position of the ice-shed. In Rendalen it is held to have been somewhere between Ottnes and Finstad, probably not far from Ottnes.

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If the boulder contents of all kinds of quaternary deposits were to indicate the same transport, we might have to accept Schiøtz's theory. The glacifluvial deposits, however, exhibit quite another picture, though. These deposits offer the best opportunity for calculating the contents of various kinds of boulders, because there is a great number of road cuts in them. As previously mentioned, the coarser material is always polygenous, and the origin of the major part of it is unknown. The difficulties are caused by the minor identifiable part.

About 5 km N of Ottnes, G. Vogt and Fr. Husebye observed a single block of anorthosite pegmatite, originating no doubt from Ottnes. It was found in a gravel-pit near the highway at Hornset. This is at variance with the ice-shed being situated N of Ottnes.

Last summer I made a few similar observations near Åmot. Along the road E of the Glåma river, about 4 km N of its confluence with the Rena river, there are a number of gravel-pits, the block-contents of which are highly interesting. Omitting the block-calculation details, the boulder and pebble material is composed as follows:

Precambrian rocks (from the SE)	10—20 %
Various sparagmites, mainly from the N arc	75—80 »
Rare types, and rocks of unknown origin	5—10 »

The contents of precambrian rocks is the important factor.

My geological experience from the "sparagmite area" of Eastern Norway enables me to exclude as possible origins the following precambrian areas: The "Spekedalen (Finstad) window", the "Atnesjø window", and the narrow autochthonous area along the E shore of the Storsjøen lake and its continuation southwards in Rendalen. The boulder types are similar neither to the rocks of the "Spekedalen window" nor to those of the "Atnesjø window", and, as for the Rendalen area, it is far too narrow and too deep down in the valley to have yielded as much as 20 % of the boulders in question. The only possibility is that they come from the large precambrian area in the SE sector, where similar rock types are abundant.

This observation, in view of those from Ottnes, discourages the assumption of a local ice-shed in the Glåmdalen valley that far south of the corresponding ice-shed in Rendalen. The most plausible explanation seems to me that part of the block material (possibly a major part) dates from an earlier glaciation period, the ice-shed having at the time been situated farther to the S or SE than was the case during the latest glaciation period.

The ice-shed situation farther SE during an earlier glaciation period than within the latest one, may even throw some light upon the granite and serpentine erratics scattered over the Rendalssølen mountain and its surroundings. The problem of their origin being but slightly touched upon by Törnebohm (1872) and Schiøtz (1892), only a few Norwegian geologists are aware of the importance of this question relating to the position of the ice-shed. The serpentine. especially, is easily spotted owing to its yellowish-brown weathering surface, but granite boulders are just as abundant upon closer invesigation. Their origin, for reasons stated below, is unknown. Had they originated from any of the well-known occurrences in the NW arc, we should expect to find erratics of associated rocks. Thus, if the serpentine boulders came from Tronfjell, we should expect erratics of the characteristic resistant gabbro types, which on Tronfjell are far more common than is the serpentine. If coming from the Røragen area, they would be associated with serpentine conglomerate, while, if they originated from any other part of the Trondheim district, we should necessarily find blocks of amphibolite and hornblende-schist among them. The complete absence of these common rock types exclude these areas as possible sources for the Rendalssølen erratics. For the same reason a western origin for the granite boulders is excluded. "Törnebohm's" suggestion (1872) of a NE origin does not fit it well, because this direction of transport is unknown so far. The sole possibility left, then, is an origin in the SE arc. Now, the erratics on Rendalssølen occur up to about 1600 m a. s. l. In the SE arc there is scarcely any occurence of similar rock types above 1000 m. An upward transport of 600—700 m implies a rising gradient of the ice surface in a SE direction. This does not correspond at all with the ice-shed just N of Ottnes suggested by the ground moraine boulders here. Consequently, I suppose the erratics on Rendalssølen date from an earlier glaciation period during which the ice-shed had a position far to the SE.

Fig. 2 illustrates some block-transports according to my field experience. Full arrows indicate a transport suggested during the last glaciation period. Broken arrows indicate the resultant ice-transport of an earlier glaciation period and the last one.

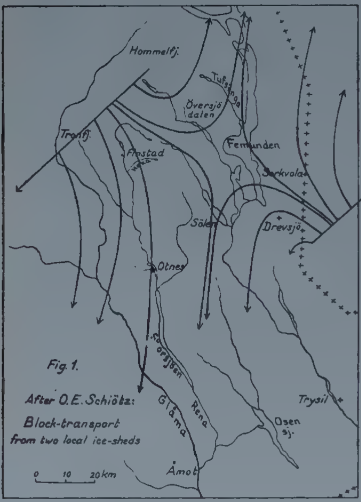
Whether this earlier period corresponds to an earlier ice-age or merely to an earlier stage during the last ice-age, remains an open question. In the latter case we should have the following succession: firstly, the ice-shed moving from the water-shed position to somewhere SE of Åmot, secondly retiring to a position N of Ottnes. This implies certain climatological conditions: if the ice-shed retired from a SE position towards the water-shed, the glacietion had to be *active* all the time, i. e., the snow-line had to be lying below the ice surface. O. E. Schiøtz has demonstrated (1895 b) that the ice-shed would retire to the water-shed under such conditions.

It is almost certain that such conditions did not occur, even during the early stage of the melting-down period. There is in Scandinavia strong evidence of a rapid change in temperature and a quick melting-down of the ice. During the "Allerød-time", for instance, we may expect the snow-line to rise to a level above the top of the ice. The ice-front retreated almost continuously from Denmark to a line southern Finland—middle Sweden—southern Norway, the so-called "Ra"-stage, from this stage (there are several steps) traces of active glaciation are found.

The "Aker-step" (from Aker near Oslo, the youngest one) in particular undoubtedly represents an advance of the ice. Mostly, the Ra-moraines, however, seem to indicate stops in the retreat rather than forward pushes of the ice-front. Unfortunately, no correlation between the Ra-stage and the position of the ice-shed has been attempted so far.

In view of the general conditions and the striking difference between the boulder composition of the ground moraine and that of the stratified deposits, I assume an interglacial age of part of the boulder material, perhaps a greater part of the enormous quantities of glacifluvial deposits found in the valleys of Eastern Norway. In this connection I want to call attention to the fact that, in 1930, that tusk of *Elephas Primigenius* was found in glacifluvial deposits near Jessheim, 35 km NE of Oslo.

The few observations pertaining to the ice-movement near the ice-shed offered in this paper are those that, in my opinion, occupy the central position in the problem. As the future studies will imply a great number of block-calculations and the surveying of an area too extensive to be covered by a single person, I hope to make other geologists interested in the question presented.



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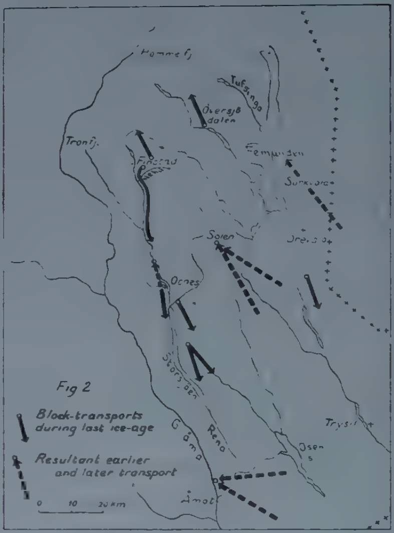

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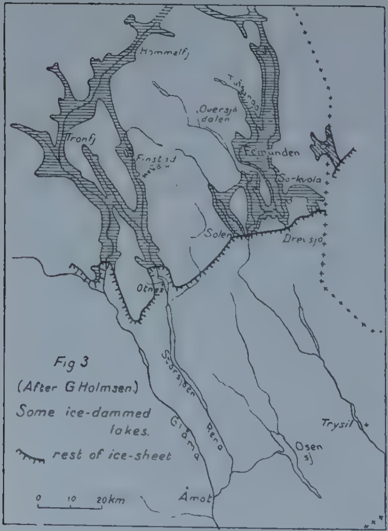

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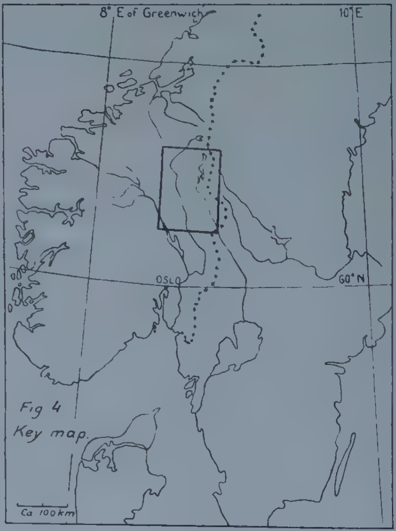

Fig. 4.

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PERMIAN VOLCANIC NECK, IGNEOUS DYKES AND FAULT ZONE IN THE ULLERN—HUSEBYÅSEN AREA, OSLO

BY

J. A. DONS

Ullernåsen and Husebyåsen, two hills of about 3 square kilometers covered with mixed forest, 5—10 km from the centre of Oslo, have been mapped geologically (scale 1 : 1000 with contour interval 1 meter) by the author. Neighbouring areas, the Fornebu peninsula to the SW and the lowland of Bærum to the W, have been investigated before by Werenskiold (1) and Sæther (2). Compare fig. 3.

In Permian time the folded beds of fossiliferous Ordovician shales and nodular limestones were pierced by a volcanic neck, now represented by 3 bodies of Oslo-essexite (subvolcanic rocks of syenodioritic composition with differentiates) which in horizontal section exhibit elliptic outlines; the longer axes being parallel to the strike of the Ordovician strata, NNE—SSW.

Later invasions consist of dykes, the composition of which ranges from diabase to quartzaplite, different types of syenite porphyries predominate.

Subsequently the area was cut by a Permian deformation zone running NNW, effecting along one of its vertical faultplanes a horizontal displacement of 200 meters southward and 50 meters downward of an eastern block relatively to a western one.

A detailed description of this area will be published in the series "The Igneous Rock Complex of the Oslo Region" (Skr. Vid.-Akad., Oslo).

The igneous material which now forms the three bodies of Oslo-essexite had the ability of crowding aside the bedrock during the intrusion. This is shown from strike and dip relations in the bedrock. It is also seen that the sedimentary rocks surrounding the northwestern

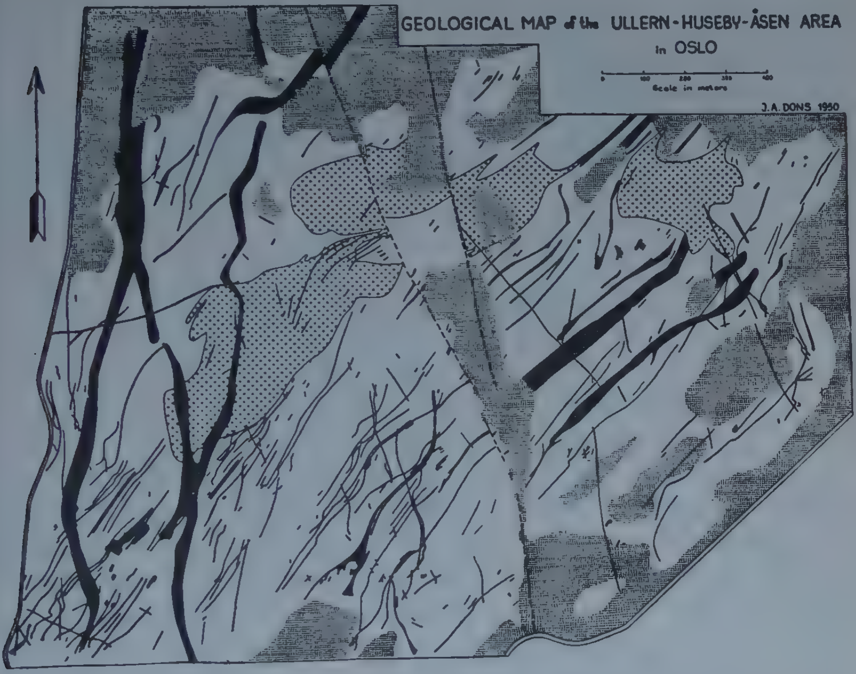

Fig. 1. Finely stippled pattern: Heavily covered areas. Dashed lines: Fault lines. Dark lines: Diabases, syenitic dykes etc. Coarsely stippled pattern: Oslo-essexite (mainly syenodiorites with both nepheline-bearing and quartz-bearing differentiates). White: Folded Ordovician shales and nodular limestones.

body (of subcircular outline) have been displaced upward during the formation of the intrusive rock. The amount of uplift at the border is 100 meters. The fact that inclusions are rare, and that there is but slight evidence of assimilation, suggests that the prosesses of crowding aside, and lifting up solved the room-problem.

In the above-mentioned body, as well as in the corresponding part on the other side of the (younger) fault, the structural elements in the rock (i. e. feldspar crystals causing platy flow structure) indicate a converted cone with steep sides. This supports the idea of the bodies of Oslo-essexite being feeding channels for volcanoes. In the adjacent districts 3 different basaltic lava flows are found, one of which probably can be correlated to the neck in the Ullern—Husebyåsen area.

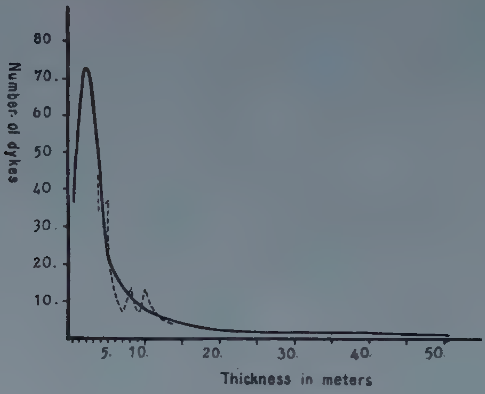

Fig. 2.

The southern part of the southwestern body was formed by successive intrusions, each of which was capable of selecting the contact between sediments and the former intrusive as the most favorable path of ascent. The rocks which represent these consecutive intrusions (akerites) are characterized by a gradual increase in the content of silica. Rocks in different parts of the eastern body exhibit two contrasted trends of differentiation: 1) towards a nepheline rich restmagma ("husebyite") and 2) towards a quartsbearing restmagma (windsorite). This fact was mentioned by Barth (3) and will in the forthcoming publication receive a fuller treatment by the present author.

365 dykes have been mapped. Dykes whose thicknesses are inferior to one meter are infrequent, and have seldom been recorded. The diagram fig. 2 shows that 2—4 meters is the normal thickness.

Some of the dykes can be traced only for a couple of meters, then they disappear under loose deposits and fail to reappear in the direction of the strike. Other dykes, however, extend for a long distance; for instance there is a dyke of mica-syenite porphyry, which in N—S direction crosses the whole area, and can be followed at least 17 km.

Wedging out and bifurcation, xenolites, vesciculation, orientation of phenocrysts, composite dykes, chilled margins and marginal zone due to "thermodiffusion" have been studied. All the dykes seem to be of the dilation type with separation (concomitant with the magmatic invation) of the dike walls in the direction normal to the strike. Lateral movements along the walls of the fissure have not been observed.

The assumed age reations which are given in the table below (oldest at the bottom) are based on 88 intersections between dykes in this area and some 120 intersections in the districts to the W and SW.

Quartz porph. 12
Diabases 99

Windsorite 3
Kullaite 1
Quartzaplite 1, Sphærulite 1
Nordmarkite porphyry 6
Syenite porphyry 22
Semitrachyte 7, Mica-syenite porphyry 2
Rhomb porphyry 7, Akerite porphyry 7
Pseudomænaite 1
Lindøite 12
Bostonite 11
Mænaite and mænaite porphyry 173

(The number after each rock indicates how many dykes of that type has been found in the Ullern—Husebyåsen area).

The petrological description of most of these dykes has been given by Sæther (2).

The oldest dyke invasion comprising the mænaite and the mænaite porphyry is the most significant one, both in number of dykes and volume. Their strike is usually NNE. They are particularly numerous within a rather well limited area shown in fig. 3. In accordance with recent investigation by the school of H. Cloos (4, 5) the star diagram constructed for mænaites and mænaite porphyries, as well as other features, seems to indicate that the area shown in fig. 3 has suffered a dome-shaped uplift just after the intrusion of the Oslo-essexite, the longer axes of the dome forming a small angle with the strike of the sediments. This uplift brought about a dilation large enough to give room for the dykes of mænaite and mænaite porphyry. The uplift probably took place in consequence of a forceful injection of magma in sheets, which now are seen as sills of mænaite and mænaite porphyry between the Precambrian gneisses and Cambrian alum shales.

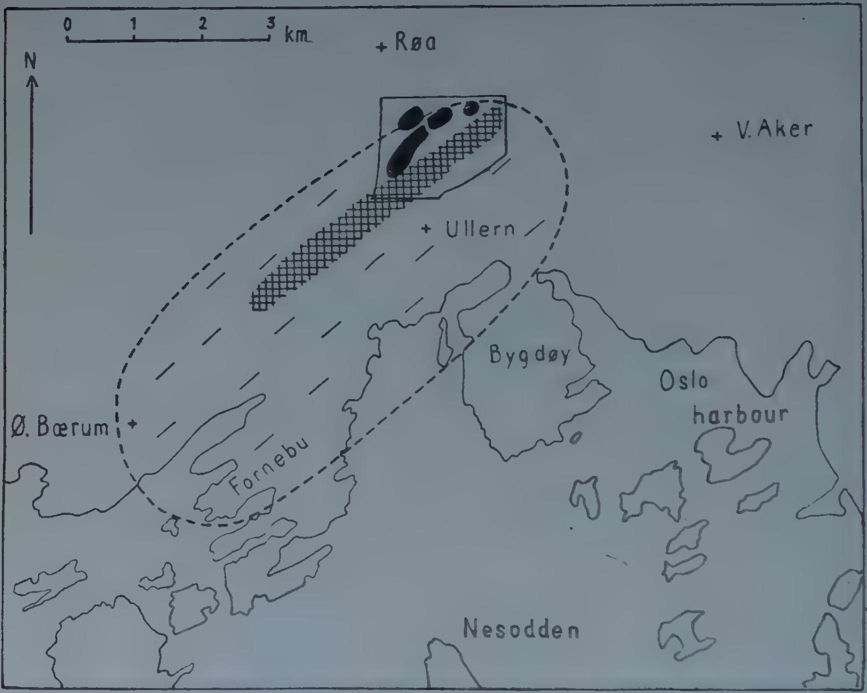

Fig. 3. Dykes of mænaite and mænaite porphyry are numerous in the area limited by the dashed line, and are particularly numerous in the shaded part. The Ullern-Husebyåsen area is indicated.

Star diagrams for younger types of dykes show that they were intruded when the tension in the earth crust had changed to some extent.

All dykes cover 17 % of the exposed area that they could invade (the area taken up by the Oslo-essexite is calculated as not invadable).

Werenskiold says that in a small area situated some kilometers to the SW, he has along a traverse of 140 meters encountered numerous dykes, the total thickness of which was 26.5 meters, corresponding to 18 %. (6). In the area to the west Sæther assumes the dykes to cover 4—6 % of the total mapped area (35 km^2) (2). This is exactly the same figure as that given by Brøgger for the islands in the inner part of the Oslofiord near the harbour and in Asker. (7).

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(7) Brøgger, W. C.: Geologisk kart over øerne ved Kristiania. Nyt Mag. for Naturv. 31, 2, 1887.

REMARKS ON THE CLASSIFICATION OF TRILOBITES

BY

GUNNAR HENNINGSMOEN

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Abstract. The classification of trilobites is discussed. No orders (or suborders), but a number of superfamilies are recognized and discussed. The Zacanthoidacea, Olenellacea, Redlichiacea, and Conocoryphacea may have developed from a common trilobite stock with dorsal shield. The Agnostacea (comprising Agnostidae and Eodiscidae) may be close to an early Redlichiacean-Conocoryphacean stock. The Asaphacea, Dikelocephalacea, Odontopleuracea, Phacopacea, and Cheiruracea are claimed to be most probably descendents of the Conocoryphacea, and the same is likely true of the Raphiophoracea. The Lichidae and Telephidae are suspected of being related to the Odontopleuracea, and so is *Pharostoma*, which may belong to a lineage between this superfamily and Calymenacea. Attention is drawn to the pattern of the glabellar furrows and the anterior sutures as features of classificatory importance, while other features, such as size of pygidium and length of eyes are not considered of as great a taxonomic value as hitherto. A list (p. 205) shows the trilobite families arranged in superfamilies. A table (Fig. 2, p. 207) sugests the possible relationships of the major groups of trilobites.

Acknowledgements.

It is a pleasant duty for the writer to render his heartiest thanks to Professor L. Størmer for his valuable advice and for friendly criticism during the preparation of this paper. The writer also expresses his appreciation and thanks to Professor A. Heintz for offering the writer the best of facilities for his research at the Paleontological Museum, and to cand. real. S. Skjeseth and cand. real. N. Spjeldnæs for friendly discussion of certain problems. Miss Jill Murray and, in part, J. A. S. Adams, have kindly revised the manuscript, and are sincerely thanked by the writer.

Introduction.

Since Stubblefield's paper on "Cephalic sutures and their bearing on current classification of trilobites" appeared in 1936, the classification of trilobites has especially been discussed by Whitehouse (1939), R. & E. Richter (1941), Størmer (1942), and lately by Rasetti (1948).

The results of several of the latest authors are combined by Rasetti (1948, p. 5), who considers a number of points as fairly well established. The writer strongly agrees with the points concerning Beecher's orders Hypoparia and Proparia; that Beecher's order Hypoparia has no phylogenetic significance, and that Cambrian families with proprian facial sutures have little in common with post-Cambrian proparian trilobites. The writer disagrees, however, with Rasetti in considering it as fairly well established that (*l. c.*, p. 7) "the distinction between the agnostids and all other trilobites is absolutely sharp: there is no known form which bridges the gap", and that (*l. c.*, p. 5) "The ancestors of the trilobites had already become differentiated into several distinct groups in the pre-Cambrian, before acquiring a hard test and being capable of fossilifization (Whitehouse, 1939)".

A few comments are presented below on these points, as well as other points of interest to the classification of trilobites. The classification is still rather provisional, and it appears at present best not to operate with more or less doubtful orders (or suborders), but rather with smaller units, as recommended by Stubblefield (1936).

Notes on Criteria of Affinity in Trilobites.

Rasetti (1948, p. 5) stresses that a phylogenetic classification of trilobites cannot be based on a single character. The writer agrees with Rasetti in this, but also with Stubblefield (1936, p. 432) that "it will probably be found that the safest criteria of affinity are collective characters developed in the axial region of the shield", and the writer has especially paid attention to the development of the glabella and its furrows. As discussed by Størmer (1942), the glabellar furrows appear to be borders between primary somites. Advanced types of glabellar furrows therefore indicate specialization of the primary somites in the cephalon. It appears likely that such a specialization is of considerable taxonomic value. It is stressed here that it is the form, direction, and relative position of the glabellar furrows that may be of importance, not so much how well they are impressed, since the latter character may vary in closely related species. In forms with smooth glabella, one has, of course, to rely entirely on other characters in tracing phylogenetic relationships.

Whereas the Agnostacea and Olenellacea (*i. e.* Olenellidae) may readily be separated from the other superfamilies, the pattern of the glabellar furrows seems to be useful in the separation of the other three early superfamilies, the Zacanthoidacea, Redlichiacea, and Conocoryphacea (Fig. 1). Four pairs of glabellar furrows are found in many early representatives of these superfamilies. In the two latter superfamilies the number is generally reduced to three, or, in the Conocoryphacea, sometimes even to only two pairs of glabellar furrows in front of the occipital furrow. This reduction appears to be connected with a relative suppression of the development of the anterior part of the glabella, as may sometimes also be suggested in a closer spacing of the two anterior glabellar furrows on both sides.

Rather characteristic of the Zacanthoidacean type is the development of four pairs of furrows, and their very diverging course, especially the very oblique course of the pre-occipital pair. The

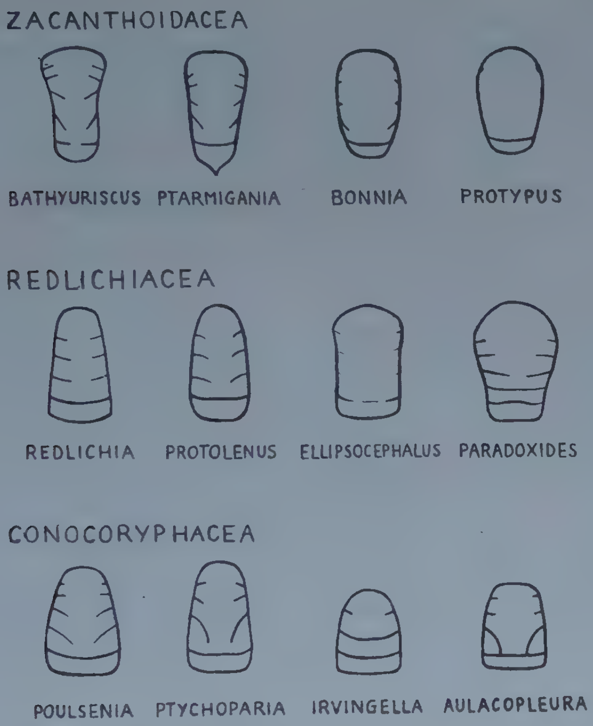

Fig. 1. Types of glabellae and glabellar furrows in the Zacanthoidacea, Redlichiacea, and Conocoryphacea.

changes in the development of the glabellar furrows in the morphological series *Ptarmigania—Bonnia—Protypus* are not regarded as a structural change in the pattern of the furrows, but a change due to the development of a more tumid and smooth glabella, — a feature paralleled in a great number of trends in trilobite evolution. The typical Redlichiacean glabella is characterized by a pattern of rather similar-looking furrows, with none of their inner ends bending forwards. In the Paradoxididae the pattern is somewhat modified because of the widening of the anterior part of the glabella, and the anterior pair of furrows may run inwards and slightly forwards. The Conocoryphacean type is well illustrated in the glabella of *Poulsenia.* Although four pairs of furrows are present, the furrows on each side of the glabella do not diverge as much as in the Zacanthoidacea. There are a great number of different trends in the Conocoryphacean type, leading to the types of the descendent superfamilies. Common trends are the suppression of the anterior pair (or two anterior pairs) of glabellar furrows, and the tendency of the inner ends of the furrows to curve more and more backwards. In late members and descendants of the Conocoryphacea the pattern of the furrows may change in a number of different ways, sometimes almost beyond recognition, such as in the Lichidae.

It has repeatedly been remarked by modern students of trilobites that the taxonomic value of the facial sutures, especially their posterior branches, has been overestimated in earlier works. A uniting of f. inst. all forms with proparian facial sutures results in the forming of a polyphyletic group, which shows that this character should be used in connection with others. Nevertheless, the development of the facial sutures is of valuable help in the classification of trilobites, and it is suggested here that a closer study of the anterior branches in Cambrian trilobites may lead to a better understanding of these forms and their relationships (cf. p. 192).

The taxonomic value of some other characters, such as long eyes, long pleural spines, and small pygidium has probably been overestimated, too, and no doubt led to the separation of closely related forms.

Trilobites with long eyes may well be closely related to forms with shorter eyes (cf. species of *Paradoxides,* as illustrated f. inst. by Westergård, 1936). Falcate and non-falcate trilobites may also be closely related, as f. inst. *Leptoplastus abnormis* Westergård, 1944 and *L. ovatus* Angelin, 1854. The dorsal shields of these appear to differ only in this feature (cf. Westergård, 1944, p. 41). Falcate and non-falcate forms occur together in other genera as well, as f. inst. *Paradoxides,* where *P. pinus* Westergård, 1936 and many other species have falcate pleura, whereas the contemporaneous *P. sjögreni* Linnarsson, 1877 has only short spines (see illustrations of both in Westergård, 1936).

It is of special interest to note that forms with small pygidium may be rather closely related to forms with larger pygidium. The small pygidium of *Paradoxides* does not differ in general structure from the larger pygidium of the closely related *Centropleura,* or the still larger pygidium of *Xystridura,* the differences being a consequence of a smaller number of segments in the *Paradoxides* pygidium. There is a grading difference only, depending on how many segments have not been detached from the transitory pygidium (cf. Størmer, 1942, p. 29). Although the ring furrows in the pygidium of *Paradoxides* may be effaced (as in the endlobe of larger pygidia), one can usually ascertain that the axis is composed of several rings.

Remarks on the Superfamilies.

Superfamily *Agnostacea* Salter, 1864.[1]

The writer quite agrees with R. & E. Richter (1941) and Westergård (1946) that the Agnostidae and Eodiscidae should be brought together in a superfamily (as suggested by Richter in 1932, and then given the name Eodiscidea), and refers to the reasoning of these authors.

Later Størmer (1942, 1949) and Rasetti (1948) have, however, quite separated the agnostids and eodiscids again.

Commenting on the Agnostidae, Størmer (1942, p. 69) writes: "It is, however, interesting to notice that the early larvae seem to deviate considerably from the protaspis of *Microdiscus,* a feature which might suggest that they belong to different Orders." He further states (1942, p. 148) that he is provisionally inclined to include the Agnostidae in the Hypoparia, and regard the Eodiscidae as probably belonging to the Proparia. In 1949 Størmer (p. 191) lists the agnostids as a superfamily of the order Hypoparia, and (*l. c.,* p. 194) the eodiscids as a superfamily of the order Proparia.

Størmer bases his separation of the agnostids and eodiscids mainly on the development of their larvae. More precisely he compares a protaspis of *Eodiscus [Microdiscus] pulchellus* (Hartt) slightly over 0.5 mm in length (described and figured by Matthew, 1896, p. 242, pl. XVII, fig. 8 d) with a specimen of the agnostid *Peronopsis fallax concinnus* (Matthew) (described and figured by Matthew, 1896, p. 216, pl. XV, fig. 8 a). According to Størmer (1942, p. 69) this latter specimen "measures only 0.5 mm in length". Matthew (1896, p. 216) writes, however: "Both the head shield and pygidium of the ½ mm size have been found of this form." Evidently Matthew means that both head shield and pygidium are 0.5 mm long, *not* the entire larva, as can be ascertained from his descriptions of other sizes, and from his figure.

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[1] cf. p. 205.

Matthew (1896, p. 244) remarks on *Eodiscus pulchellus:* "In the ½ mm stage of the head shield the glabella is already near the normal form in the adult —". This applies just as well to the 0.5 mm long cephalon of *Peronopsis fallax concinnus.* Whereas furthermore a 0.5 mm long *larva* has been found of *Eodiscus pulchellus,* no corresponding early stage of *Peronopsis fallax concinnus* has been described.

So far as the material of these two species is concerned, there is at present nothing to indicate that the larva of the agnostids deviates considerably from that of eodiscids. The writer has discussed this matter with Prof., dr. L. Størmer, who agrees with the writer that this impairs Størmer's argument for a separation of the agnostids and eodiscids.

Unfortunately no early larvae of agnostids have yet been described, and the writer has searched for them in vain in material of agnostids from the Cambrian in Norway. The larval development of the Agnostidae is too imperfectly known to allow a full comparison with that of the Eodiscidae, but the available evidence gives no reason at present for assigning these families to different orders or superfamilies. On the contrary, what is known of the larval development of the Agnostidae agrees well with that of the Eodiscidae.

Rasetti separates the agnostids and eodiscids on other ground than Størmer does. According to Rasetti (1948, p. 7) the chief distinguishing characters of the agnostids are: "(1) the specialization of the pygidial segments; (2) the probable constant number of segments represented in the pygidium; (3) the constant number of thoracic segments; (4) the complete lack of cephalic sutures in all forms."

One may comment on Rasetti's points (2), (3), and (4) that features which varies in species of one group of animals, may well have become fixed in another, closely related group. In the case of the agnostids the number of thoracic segments has become fixed at two; the number of pygidial segments has possibly become fixed; and they have all no facial sutures. This rare combination of characters shows that the agnostids are most probably a monophyletic group, and that they may well have developed from the eodiscids where these characters are variable (having facial sutures developed or not, 2 or 3 thoracic segments, and probably a variable number of segments in the pygidium). In particular it may be noticed in connection with point (2) that a constant number of pygidial segments may be suspected also in other, at least minor groups of trilobites (as in some groups of olenids); with point (3) that a constant number of thoracic segments is also known in other trilobite families (*e. g.* Asaphidae); with point (4) that since complete lack of cephalic sutures is known in some eodiscids, this character seems to be a uniting, rather than a separating feature of the agnostids and eodiscids.

As to point (1) one may remark that if the pygidial segments of the agnostids are specialized, one may expect them to have developed from forms with less specialized segments, like f. inst. eodiscids. The same may be argued for a supposed "development of particular anatomic features of the portion of the animal covered by the pygidial shield." The pygidial shield, though characteristic, does not seem to differ in general structure from that of other trilobites. The pleural areas of the agnostid pygidium show no furrows, but this is known in a number of different trilobites (*e. g. Illaenus*). The posterior rings of the axis form an end-lobe, as in many other trilobites. The first ring in the axis is of a common type, whereas the second ring often has a node or spine, and is sagitally longer and often transversally narrower than in the first ring. A rather similar axis is also known in other trilobites, as f. inst. *Amphilichas latifrons* Warburg, 1925. In some agnostids the axis has no ring furrows, whereas in others there may be three rings and an end-lobe. It is of interest to note that in some eodiscids all the rings in the axis bear axial spines or nodes (f. inst. *Eodiscus borealis* Westergård, 1946). One may well imagine that the agnostid pygidium deveoped from a type like that of the eodiscids.

As advocated by R. & E. Richter (1941, p. 20) the Agnostidae probably developed from the Eodiscidae. It may be recalled that the characteristic glabella of the Agnostidae is nearest to that of some Eodiscidae, as pointed out by several authors, and recently by Shaw (1950, p. 588). There appears to be no reasons for excluding the Agnostidae from the trilobites, as proposed by Resser (1938), and they hardly deserve a taxonomic group of higher rank than the orders Olenellidae, Opisthoparia, Proparia, and Eodiscidea, as Rasetti (1948, p. 7) thinks they do.

An inclusion of the agnostids in an order Hypoparia can hardly be maintained when the affinities between the agnostids and eodiscids are recognized, unless Hypoparia is regarded as a polyphyletic "order", as indicated by Størmer (see f. inst. his text-fig. 18, p. 149, 1942). Another reason for the exclusion of the agnostids from the Hypoparia is the failure in detecting any cephalic sutures in the agnostids (and blind eodiscids) (Stubblefield, 1936, p. 419, Rasetti, 1948, p. 6), since Hypoparia, as defined by Størmer (1949, p. 152), includes the trilobites with marginal, supramarginal or ventromarginal? suture.

Eodiscids with facial sutures resemble early Conocoryphacea so much that it suggests relationships. The proparian facial sutures found in eye-bearing forms of Eodiscidae, may be ascribed to arrested development.

Superfamily *Zacanthoidacea* Richter, 1932.

Rasetti (1948, p. 8) unites Richter's two superfamilies Zancanthoididea and Bathyuriscidea.[1] The writer quite agrees with Rasetti that *Zacanthoides* and *Bathyuriscus* may be placed in the same superfamily, and had arrived at the same conclusions before Rasetti's paper was available to him.

Richter (1932) assigns the following families to the Zacanthoididea: Lichidae, Odontopleuridae, Remopleurididae, Zacanthoididae, Ceratopygidae, and Oryctocephalidae. To the Bathyuriscidea (R. & E. Richter, 1941: Corynexochidea) are assigned: Bathyuriscidae (1941: Corynexochidae), Scutellidae, and Illaenidae. Kobayashi (1935) includes a number of additional families (Komaspididae, Telephidae, Pagodiidae, Damesellidae, Lloydiidae, Leiostegiidae), which may safely be removed again since they have all a Conocoryphacean glabella and cranidium (cf. p. 177). Furthermore the Remopleurididae and Ceratopygidae should be excluded from the Zacanthoidacea. The Remopleurididae most probably belong with the

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[1] Rasetti applies the name Bathyuriscidea for this enlarged superfamily. Kobayashi (1935) assigns *Bathyuriscus* to the Dolichometopidae of his suborder Corynexochida, altered by R. & E. Richter (1948, p. 35) to superfamily Corynexochidea. Rasetti (1948, p. 19) does not include *Bathyuriscus* and *Dolichometopus* in the same family, and consequently retains the name Bathyuriscidea. However, if the rule of priority is applied to superfamilies (cf. p. 204), Zacanthoidea Richter, 1932 (p. 852, 2nd column, line 6) has priority over both Bathyuriscidea Richter, 1932 (p. 852, 2nd column, line 18) and Corynexochidea Kobayashi, 1935, and is therefore used here, in the revised form Zacanthoidacea.

Richarsonellidae (p. 199). *Ceratopyge* and *Albertella* were earlier considered to be related genera. As pointed out by Stubblefield (1936, p. 436), the time interval between the presence of these two genera is considerable, and the resemblance too superficial to be important. The position of the Ceratopygidae is discussed below (p. 196). The Lichidae and Odontopleuridae may be assumed to be descendants of the Conocoryphacea (cf. p. 200) and therefore excluded from the Zacanthoidacea. Rasetti (1948, p. 8) is only concerned with the Cambrian families, and recognizes the Corynexochidae, Bathyuriscidae, Dorypygidae, Zacanthoididae, and Oryctocephalidae as members of the superfamily. Whittington (1950 b, p. 547) considers that the Styginidae should be placed in the same superfamily, and the present writer shares this view.

According to Rasetti (1948, p. 8) the Zacanthoidacea (*olim* Bathyuriscidea) are characteristized first of all by a glabella that occupies most of the length of the cephalon and expands toward the front, and a number of thoracic segments not exceeding 10. The form of the glabella varies between a smooth egg-shaped glabella as in *Protypus* and a concave-sided glabella as in *Bathyuriscidella*. When the glabellar furrows are developed, these are, however, also very characteristic. There are usually 4 pairs, the furrows on each side of the glabella diverging inwards. The posterior two pairs point inwards and backwards, the anterior two, which are shorter, point inwards and forwards. The majority of the Zacanthoidacea have opisthoparian facial sutures, but a few forms have no dorsal sutures, as *Acontheus* Angelin, 1854 (see Westergård, 1950, p. 8).

The following families are here assigned to the Zacanthoidacea: Corynexochidae (and its probable synonyms Ptarmiganiidae, see Rasetti, 1948, p. 20, and Bathyuriscidae, see Kobayashi, 1935, p. 132), Dorypygidae (and its probable synonym Kooteniidae, see Rasetti, 1948, p. 13), Styginidae, Illaenidae, and Scutellidae (= Eobronteidae). Probably the Oryctocephalidae (and probable synonym Lancastriidae) also belong here.

The family Lancastriidae embraces a single genus, *Lancastria* Kobayashi, 1935 (not Howell & Resser, cf. Resser & Howell, 1938, p. 229), with one described species, *L. roddyi* (Walcott, 1912). Although it has falcate pleural spines, this species has a typical oryctocephalid glabella. A species quite possibly congeneric with it is the rather similar *Oryctocephalops frischenfieldi* Lermontova, 1940.

Kobayashi (1935, p. 129) and Resser & Howell (1938, p. 229) suggest that *Lancastria* is related to *Oryctocephalus,* and in the writer's opinion the Lancastriidae should be considered a synonym for the Oryctocephalidae. The Oryctocephalidae have usually been assigned to the Zacanthoidacea, with which they share the long, not tapering glabella. The Oryctocephalidae differ, however, from the other families assigned to this superfamily in that they may have more than 10 thoracic segments and the eyes further removed from the glabella. Though more or less pit-like, at least the posterior pair of glabellar furrows may be united across, thus differing from the oblique posterior pair in the Zacanthoidacea. Nevertheless, the Oryctocephalidae resemble more the Zacanthoidacea than any of the other superfamilies, and are here, doubtfully, assigned to the Zacanthoidacea.

Superfamily *Olenellacea* (Swinnerton, 1915) R. & E. Richter, 1941.

In this superfamily R. & E. Richter (1941) place the families Olenellidae, Redlichiidae, Olenopsididae, and Paradoxididae. If the absence of dorsal sutures in the Olenellidae is primary, this family should probably not be placed in the same superfamily as the three other families.

Størmer's studies (1942) on the larval development of the trilobites leads him to the conclusion that the facial sutures in trilobites are homologous with a primary marginal suture in the larvae. Homologizing the perrostral suture of the Olenellidae with the primary marginal suture, he concludes that the Olenellidae are very primitive trilobites, and assigns them as the sole family to the order Protoparia, in which the absence of facial sutures is primary. In this connection an opisthoparian (a paradoxidid) from Australia, *Xystridure saint-smithi* (Chapman) is of considerable interest. Whitehouse shows (1939) that it has a rostrum and a perrostral suture quite like those in olenellids,[1] as well as facial sutures (of the *Paradoxides* type).[2] If the facial sutures are homologous with a primary suture as claimed by Størmer (1942, p. 144), the perrostral suture in *Xystridura* (and most probably also in the Olenellidae) is not homologous with a primary marginal suture. This means that the family Olenellidae need not be regarded as primitive because of its perrostral suture.

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[1] *Redlichia idonea* Whitehouse, 1939 is supposed to have a similar rostrum and perrostral suture.

[2] This also has some bearings on Raw's theories (1937, p. 590) on the connections between the procranidial spines, the anterior branches of the facial sutures, the connecting sutures, and the perrostral suture.

The writer is inclined to believe that the Olenellidae may be specialized rather than primitive forms with regard to the sutures, and that possibly they may have developed from ancestors with dorsal sutures. However, this problem is still an open question, and at present it appears best to restrict the superfamily Olenellacea (*olim* Olenellidea) to the Olenellidae, as proposed by Poulsen (1927) and adopted by Størmer (1949). The Olenellidae have a glabella tapering forwards, or a club-shaped glabella, the latter type possibly being an advanced feature. The likeness in thorax and pygidium of the Olenellidae and Redlichiidae is striking. The structural plan of their cephala is also very much the same, save the lack of dorsal sutures in the Olenellidae. These similarities suggest affinities.

Superfamily *Redlichiacea* Richter, 1932.

The superfamily Redlichiidea was established by Richter for the families Redlichiidae, Paradoxididae, and Olenellidae. Later it was regarded by R. & E. Richter (1941) as a synonym of Olenellacea (Swinnerton, 1915). Størmer (1949) restricts the latter to embrace the Olenellidae only, and revives Richter's name Redlichiidea for the Redlichiidae and allied. For reasons stated above, the writer follows Størmer in recognizing both superfamilies.

Forms which have been assigned to the Redlichiacea have more or less olenellid-like pygidium and thorax (small pygidium and many thoracic segments, often provided with axial nodes or spines, and often with falcate pleura), and usually with long, olenellid-like eyes. These characters are often considered primitive, and of significant taxonomic importance. As discussed above (p. 178) their taxonomic value may, however, be somewhat overestimated. It appears that "primitive-looking" trilobites, representing different phylogenetic lineages, have been assigned to the Redlichiacea. Kobayashi (1935, p. 81) includes the additional families in "Mesonacida": Zacanthoididae, Kainellidae, Remopleurididae, Ceratopygidae, Olenopsididae, Lancastriidae, and Burlingiidae. R. & E. Richter (1941, p. 33) remove these families again (except the Olenopsididae) without further comments. The Zacanthoididae may be removed since they clearly belong to another superfamily, namely the Zacanthoidacea (cf. Rasetti, 1948, p. 8). Both the Kainellidae and Remopleurididae may be removed, as they belong with the Richardsonellidae (cf. p. 199), and so may the Ceratopygidae, which are here assigned to the Asaphacea (cf. p. 196). The Lancastriidae have been placed in this superfamily probably because of the falcate pleura and small pygidium, but are here considered a synonym of the Orytocephalidae (p. 183), doubtfully placed in the Zacanthoidacea. The Burlingiidae constitute a family whose relationships with other trilobites is uncertain, but they are here tentatively placed in the Conocoryphacea (p. 194). For reasons stated below, the Redlichiidae (and possible synonym Olenopsididae), Ellipsocephalidae (and probable synonym Protolenidae), and Paradoxididae are here included in the Redlichiacea.

The Redlichiidae have a small, *Paradoxides*-like pygidium, numerous thoracic segments with axial node (usually with one or more developed as long spines), falcate pleura, long eyes, and a glabella tapering evenly forwards, with three pairs (sometimes traces of a fourth, anterior pair) of rather similar, evenly spaced, sub-parallel glabellar furrows. The facial sutures do not meet in front. The type genus *Redlichia* Cossmann, 1902 and its subgenus *Redlichops* R. & E. Richter, 1941, can be safely assigned to the Redlichiidae, also *Neoredlichia* Saito, 1936, and *Mesodema* Whitehouse, 1939. It is possible that the latter may be a synonym of *Redlichia,* as suspected by R. & E. Richter (1941, p. 14). Probably *Redlichina* Lermontova, 1940 also belongs here. *Bergerionellus* Lermontova, 1940 is assigned to the Redlichiidae by R. & E. Richter (1941), but resembles also the Protolenidae (cf. p. 189).

The family Olenopsididae was established by Kobayashi (1935, p. 129) for the accomodation of *Olenopsis* Bornemann, 1891. This genus has often been compared with *Redlichia,* with which it shares the same type of pygidium, thorax (though no axial spines have been recorded in *Olenopsis*), and cranidium, except that *Olenopsis* has shorter eyes, and, as is common in this case, wider post-ocular parts of the fixed cheeks. Since difference in length of the eyes need not be any objection to a close affinity (cf. p. 178), it appears probable that *Redlichia* and *Olenopsis* are closely related, in the writer's opinion to the extent that the Olenopsididae should be considered a synonym of (or perhaps subfamily of) the Redlichiidae. Whitehouse (1939, p. 196) established the Metadoxidinae as a new subfamily of the

Paradoxididae, to accomodate two Sardinian genera, *Metadoxides* Bornemann, 1891 and *Anadoxides* Matthew, 1899, and a third genus, *Catadoxides* Matthew, 1899, from Newfoundland. None of them have the club-shaped glabella typical of the Paradoxididae, and in the writer's opinion they should not be included in that family, which without them form a well-defined unit. *Metadoxides* and *Anadoxides* occur associated with *Olenopsis*, and probably may be related to this genus. *Metadoxides* (as restricted by Matthew, 1899) is poorly known, but appears to differ from *Olenopsis* in having a longer glabella and probably no falcate pleura. *Anadoxides* bears much resemblance to *Olenopsis*, but appears to have a pygidium of the elliptocephalid type (cf. p. 189). *Catadoxides* is not well known, and it is uncertain whether it should be assigned to the Redlichiidea or not.

The genera *Saukianda, Perrector, Resserops*, and *Eops*, described by R. & E. Richter (1940) from the *Saukianda* Beds in Andalusia (Spain), may, for reasons discussed below, be assigned to the Redlichiacea, probably the Redlichiidae. *Perrector, Resserops*, and *Eops* have a glabella of the *Redlichia* type. In the writer's opinion the differences[1] between these three genera are at least not above specific level. *Resserops* and *Eops* are here regarded as synonyms of *Perrector*, which is assigned priority on the basis of precedence in page. The resemblance of the related genus *Saukianda* to the Dikelocephalidae was noted by R. & E. Richter, and all the above-mentioned forms from Andalusia were assigned to that family. *Saukianda* admittedly is rather like the Dikelocephalidae, but there appears to be at least one important difference throwing doubt on the supposed affinities, namely the course of the anterior branches of the facial sutures. While these unite anteriorly in the Dikelocephalidae, they hardly seem to even converge in *Saukianda* (as in *Redlichia*), as far as can be judged from the careful illustrations. The dikelocephalid appearance of *Saukianda* is especially brought out by the confluent pre-occipital pair of glabellar furrows, combined with a poor development of the glabellar furrows in front. This is, however, a character also found in a number of other trilobite groups, f. inst. in *Irvingella, Elvinia*, and *Ctenopyge*. It is of special interest here that species of

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[1] Absence or presence of a very small pre-glabellar field, narrower or wider forms, absence or presence of a pair of pits in the anterior furrow, or slight variation in their location.

Ctenopyge may either have a "dikelocephalid" type of development of the glabellar furrows, or a more "ordinary" type (see illustrations of *Ctenopyge* in Westergård, 1922, pls. XI and XII). Consequently the development of the glabellar furrows in *Saukianda* need not exclude the possibility of close affinities between this genus and *Perrector.* A comparison of these genera leaves little doubt that they are closely related. The general structure of the dorsal shields of *Saukianda* and *Perrector* agree very well. The resemblance between the Andalusian forms and *Redlichia* has already been pointed out by Wilson (1948, p. 599). R. & E. Richter (1949, p. 219) regard, however, the relative size and number of segments in the pygidium as decisive differences from the Redlichiidae. As advocated above (p. 178), the taxonomic value of these characters has probably been overestimated, and the writer confidently places *Saukianda* and *Perrector* in the Redlichiacea. The similarities between *Saukianda* and the Dikelocephalidae should probably be ascribed to morphological convergence. There is little chance that the Dikelocephalidae have developed from the *Saukianda*-group, as the time interval between their occurrence is rather long.

With the exception of the doubtful fragments assigned to *Koptura?* and *Tellerina?,* the other trilobites described from the *Saukianda* Beds (R. & E. Richter, 1950), namely *Strenueva* and "*Camaraspis*" species, belong to the Ellipsocephalidae. Accepting the affinities between *Saukianda* and *Redlichia,* the disputed age of the *Saukianda* Beds may fairly safely be taken as (probably uppermost) Lower Cambrian, as already suggested by Wilson (1948, p. 599). This appears to be a satisfactory settling of the age problem of these beds, admirably discussed by R. & E. Richter (1940, 1949), who had restricted the possibilities to Upper or Lower Cambrian.

From the family Ellipsocephalidae R. & E. Richter (1948, p. 25) split off the Protolenidae, which are stated (*l. c.,* p. 26) to differ from the Ellipsocephalidae first of all in the greater divergence of the anterior branches of the facial sutures. In the type species of *Protolenus* Matthew, 1892, *P. elegans* Matthew (see Walcott, 1913, pl. 24, figs. 4—5, or Cobbold, 1931, pl. XXXIX, fig. 23) the anterior branches are almost parallel, similar to those in *Ellipsocephalus hoffi* Schlotheim, 1823, the type species of *Ellipsocephalus* Emmrich, 1839 (see f. inst. Barrande, 1852, pl. 10, fig. 26). Admittedly *Bigotina* Cobbold, 1935 and *Lusatiops* R. & E. Richter, 1941, assigned to the

Protolenidae by R. & E. Richter, have more diverging branches of their facial sutures, but this is also the case with forms belonging to the Ellipsocephalidae, as *Ellipsocephalus germari* Barrande, 1852 (see fig. 1, pl. XVII in Pompeckj, 1896; and Westergård, 1950, p. 10 for the inclusion in *Ellipsocephalus* of this species). There do not thus seem to be any important differences in the development of the anterior branches of the facial sutures in the two families. One might argue that the glabella of *Protolenus* differs from that of *Elliptocephalus,* as the latter tends to be slightly expanded at its anterolateral angles. *Strenuella (Ellipsostrenua) gripi* Kautsky, 1945, shows, however, intraspecific variations between a protolenid and ellipsocephalid type of glabella. Since *Protolenus* appears to be closely related to *Ellipsocephalus,* the family Protolenidae does not seem necessary.

The pygidium of *Ellipsocephalus* is small, but differs from the *Paradoxides*-type in being markedly wider than long, with wide pleural areas, and having an axis reaching the posterior border. The pygidium of *Protolenus* does not seem to be known. The pygidium described by Schwartzbach (1934) as belonging to *Protolenus lusaticus* can no longer be admitted, since R. & E. Richter (1941) made this species the type of a new genus, *Lusatiops.* As described by R. & E. Richter (1941, p. 42) this pygidium appears *Ellipsocephalus*-like. *Lusatiops* has a cranidium intermediate between those of *Redlichia* and *Protolenus,* long genal spines, and long pleural spines, and was first assigned to the Redlichiidae by its founders, but was transferred, because of its pygidium, to the Protolenidae when this family was erected (1948). On the other hand, *Bergerionellus* Lermontova, 1940, which has a *Protolenus*-like cranidium, was assigned to the Redlichiidae on the account of its olenellid-like pygidium. Whether *Lusatiops* and *Bergeroniellus* are placed in the Redlichiidae or Ellipsocephalidae, they seem to be intermediate forms, making it difficult to draw any border between these two families. (See also illustrations of Redlichiidae and Ellipsocephalidae in Kobayashi, 1944). *Palaeolenus* Mansuy (1912), which Kobayashi (1935) and R. & E. Richter (1941) place in the Ellipsocephalidae, has been shown by Yen-Hao Lu (1941) to have a pygidium of the olenellid type. Otherwise *Palaeolenus* agrees so well with the Ellipsocephalidae, especially in the glabella, that probably it should not be removed because of its pygidium. In the writer's opinion the relations between the *Redlichia*-

pygidium and *Ellipsocephalus*-pygidium may be compared with the relations between the pygidia of *Paradoxides* and *Centropleura,* and thus need not be of very great taxonomic importance (cf. p. 178).

The Ellipsocephalidae agree with the Redlichiidae in having a simple pattern of glabellar furrows, with three (sometimes four) rather similar-looking, evenly spaced, and usually subparallel furrows. This, and the other similarities mentioned, appear to justify the inclusion of the Ellipsocephalidae and Redlichiidae in the same superfamily. The name Redlichiidea Richter, 1932 (p. 852) has precedence in page to Ellipsocephalidea Richter, 1932 (p. 854) (cf. p. 204). The shape of the glabella is more variable in the Ellipsocephalidae than in the Redlichiidae. It varies between the tapering glabella of *Lusatiops* (which possibly should be assigned to the Redlichiidae), the more parallel-sided glabella in *Protolenus,* and the more or less club-shaped glabella in *Ellipsocephalus, Ferralsia* Cobbold, 1935, and *Palaeolenus.*

The Paradoxididae have an even more club-shaped glabella. The cranidium of *Paradoxides,* with its long glabella, may to some extent remind one of the cranidium in the Zacanthoidacea. The preoccipital pair of glabellar furrows does not, however, have the very characteristic oblique course of the typical Zacanthoidacea. The pattern of the glabellar furrows in *Paradoxides* may be looked upon as an advaned type of that found in other Redlichiacea, especially *Palaeolenus,* which approaches *Paradoxides* also in the shape of the glabella. Meraspid cranidia of *Paradoxides* (Westergård, 1936, pls. IV and V) have a well developed pre-glabellar field, not known in the Zacanthoidacea. On the other hand, meraspid cranidia of *Paradoxides* resemble the adult cranidium of *Palaeolenus.* The thorax and pygidium of *Paradoxides* are very like those of *Redlichia* and *Olenopsis.* The number of thoracic segments is greater than 10 in *Paradoxides,* whereas this is not known in typical Zacanthoidacea (Rasetti, 1948, p. 8). It appears rather certain that the Paradoxididae are slosely related to the other Redlichiacea, and they are included in this superfamily.

The Redlichiacea may remind one of some early members of the Zacanthoidacea, but the characteristic glabella readily distinguishes the latter. Nevertheless, *Redlichia* has often been compared with *Albertella* and *Zacanthoides,* and they have so many features in common, that they must have developed from the same trilobite stock. There can, however, hardly be any doubt that the Redlichiacea are more closely related to the Conocoryphacea. The latter usually have a more advanced pattern of the glabellar furrows (p. 177), but early members, like the Alokistocaridae, may be difficult to separate from the Redlichiacea. The Lower Cambrian genus *Proliostracus* Poulsen, 1932 is assigned to the Ellipsocephalidae by its founder, but is here believed to belong to the Conocoryphacea, mainly because of its glabellar furrows. The great similarities between the Redlichiacea and Olenellacea have already been pointed out (p. 185).

Superfamily *Conocoryphacea* Swinnerton, 1915.

This superfamily was named Ptychopariidea by Richter (1932), but recognizing it as a synonym for Swinnerton's suborder Conocoryphidea, the name of the superfamily was changed to Conocoryphidea by R. & E. Richter in 1941. The following families are included by R. & E. Richter (1941): Conocoryphidae (Conocoryphinae + Ptychopariinae), Solenopleuridae, and Harpidae.

In another superfamily, Olenidea Swinnerton, 1915, of which Ellipsocephalidea Richter, 1932 is regarded a synonym by R. & E. Richter, 1941, the following families have been included by R. & E. Richter (1941, 1948): Olenidae, Ellipsocephalidae, Protolenidae, and Otarionidae. Whitehouse (1939) suggests that the Olenidae arose from a ptychoparid stock, and unpublished studies by the present writer seem to confirm the Conocoryphidean descent, though the Olenidae probably did not develop from *Lyriaspis* via Papyriaspinae as suggested by Whitehouse. The Olenidae are thus not closely related to the Ellipsocephalidae (and probable synonym Protolenidae), which are here assigned to the Redlichiacea (cf. p. 190). As remarked by Whitehouse (1939, p. 216), the very name *Protolenus* has tended to draw undue attention to a connection with the Olenidae. The Otarionidae do not have the anterior branches of the facial sutures meeting in front as the Olenidae, and have not developed from the Olenidae. The Otarionidae have no doubt developed from earlier Conocoryphacea, and they are here placed in the superfamily Conocoryphacea. This leaves only the Olenidae in the superfamily Olenidea, which is abandoned here. Because of their most probable Conocoryphacean descent, the Olenidae also are here placed in the Conocoryphacea, though there is a possibility that later it may turn out to be more convenient to assign the Olenidae to a superfamily developed from the Conocoryphacea (see below). It may be remarked that Conocoryphacea Swinnerton, 1915 should be retained as the name of the superfamily, even when it includes the Olenidae, typical family of Swinnerton's (1915) group Olenina, since Swinnerton regarded Olenina as a section of Conocoryphida.

The Conocoryphacea have primarily a glabella tapering forwards, but it may be more or less transformed in different trends, and in their descendants. The typical Conocoryphacean glabella has three (sometimes four) pair of glabellar furrows, thus reminding one of the Redlichiacea. Their pattern is, however, not so simple as in the Redlichiacea. While the latter have rather similar-looking and sub-parallel pairs of glabellar furrows, the Conocoryphacea usually have a marked angle of divergence between the glabellar furrows on each side. Moreover the posterior pair (or two pairs) of glabellar furrows are markedly longest and strongest in the Conocoryphacea, where there is a strong tendency to shorten the distance between the anterior furrows, and for the inner ends of the furrows to turn backwards. In more advanced Conocoryphacea, and especially in their descendants, the differentiation of the glabellar furrows may go very far. In some cases only two pairs of glabellar furrows are developed in front of the occipital furrow (*e. g. Irvingella*). When four pairs of glabellar furrows are present (in early forms like *Poulsenia*), the direction of the glabellar furrows reminds one of those in the Zacanthoidacea.

The facial sutures in the Conocoryphacea have a tendency to converge in front and cross the anterior border at a very low angle. In some forms the anterior branches of the facial sutures meet in front axially, and may continue as a median suture across the doublure, as f. inst. in the Elviniidae (cf. p. 199), and possibly also in other families such as the Anomocaridae (cf. p. 196), as well as in the superfamilies Asaphacea and Dikelocephalacea, which are both regarded as descendants of the Conocoryphacea (cf. pp. 195, 197). The facial sutures meet in front axially in the Olenidae also, but, having no doublure, a median suture is not developed. It appears probable that a better knowledge of the sutures in Cambrian forms paired with a careful study of the pattern of glabellar furrows may serve as a base for a classification of the Cambrian Conocoryphacea. This is, however, beyond the scope of this paper, but no doubt of great interest to the classification of the trilobites as a whole. It may be that later the Olenidae and other Conocoryphacean families with the facial sutures meeting in front will be placed in another superfamily, derived from the Conocoryphacea, when more is known about the origin of this type of sutures. Till then, these families may safely be included in the Conocoryphacea.

Believing that Lower Cambrian trilobites like *Ptychoparella* and other forms with Conocoryphacean type of glabella should be included in the Conocoryphacea, the following Cambrian families may fairly safely be assigned to this superfamily: Agraulidae, Alokistocaridae, Andrarinidae, Anomocaridae, Asaphiscidae, Blountiidae, Burnetiidae, Cedariidae, Conocoryphidae, Crepicephalidae, Damesellidae, Elviniidae, Emmrichellidae, Komaspididae, Lejostegidae, Liostracidae, Llanoaspididae, Lloydiidae, Marjumiidae, Nereidae, Olenidae, Pagodiidae, Plethopeltidae, Solenopleuridae and Tollaspidae. No doubt some of these families will later be regarded as synonyms of others, or regarded as subfamilies. A rather careful study of the extensive literature on the genera included in these families, especially the type genera, has convinced the writer that these families are all related, and that intermediate forms exist between the simpler types (as Alokistocaridae and Conocoryphidae) and more advanced families.

Cambrian proprian families. The Menomoniidae resemble so much contemporaneous opisthoparian Conocoryphacea, not the least in their glabella, that they must be closely related, and are here regarded as belonging to the superfamily Conocoryphacea. The same applies to the Norwoodiidae, which were placed in a separate superfamily, Norwoodiidea, by Richter (1932), whereas the Menomoniidae were regarded as members of the same stock as the Conocoryphidae (*olim* Ptychopariidae) by Warburg (1925), a view shared by Richter (1932). Raw in 1925 (p. 316) has already proposed that not only the Menomoniidae, but also the Norwoodiidae are closely related to the Conocoryphidae. Kobayashi (1935) also recognizes relationships between the Conocoryphidae and the Norwoodiidae, placing them in an order Ptychoparida. Other Cambrian proparian trilobites have been described, that also seem to have developed from opisthoparian Conocoryphacea. Most probably also the proparian Cheiruracea and Phacopacea are descendants of opisthoparian Conocoryphacea. It is not surprising that the proprian condition seems to have developed in different trends, since it may be due to arrested development, as suggested by Stubblefield (1936, p. 430). It does not seem necessary, or even advisable, to erect a new superfamily for every off-shoot of the Conocoryphacea, which have developed proparian sutures in the adult. The Burlingiidae are some minute proparian trilobites whose family connections are doubtful. Their short glabella and well-developed pre-glabellar field seem to exclude relationships with the Zacanthoidacea, and suggest affinities with the Redlichiacea and Conocoryphacea. Since the development of proparian forms is well known in the Conocoryphacea, the Burlingiidae are, tentatively, assigned to this superfamily. The Burlingiidae were allowed a separate superfamily, Burlingiidea, by Richter (1932).

The Shumardiidae, with no dorsal sutures, constitute another small family whose affinities have not yet been determined. The short glabella and the ornament of the thorax and pygidium are features not known in the Zacanthoidacea, but common in the Conocoryphacea. Although probably not closely related to *Conocoryphe,* as suggested by Pompeckj (1902, p. 7), nor to the Olenidae, as proposed by Moberg (1890, p. 7), the Shumardiidae are here, doubtfully, assigned to the Conocoryphacea.

Post-Cambrian trilobites that may fairly safely be assigned to the Conocoryphacea are, besides representatives of "Cambrian" families (*e. g.* Olenidae), the Otarionidae, Proetidae, and Harpidae, all of which have a glabella that is only a slight modification of the typical Conocoryphacean glablella. The Proetidae, and especially the closely related (Pribyl, 1947) and slightly older Otarionidae show so many features in common with the Cambrian representatives of the Conocohyphacea, that they may be assigned to this superfamily, if one does not prefer to place them in the superfamily Proetacea, as proposed by Kobayashi (1935, p. 83). The Harpidae, with no dorsal sutures, have long been placed with the Conocoryphidae and Solenopleuridae. Whittington (1950, p. 6) is unable to offer any new suggestion concerning the relationships of the Harpidae and other families. It seems unnecessary to place the Harpidae in a superfamily Harpedacea, as proposed by Kobayashi (1935). One may recall that there are other Conocoryphacean families containing forms with no dorsal sutures, as the Conocoryphidae and Harpididae. The Entomaspididae may possibly also belong to the Conocoryphacea. *Loganopeltis* Rasetti, 1943 is suggested to belong to the Harpidae by Rasetti (1945, p. 9), but is excluded from this family by Whittington (1950, p. 5), who later (1950 c, p. 303) suggests that *Loganopeltis,* *Loganopeltoides* Rasetti, 1943, and *Harpides* Beyrich, 1864 may be assigned to a family Harpididae. They do, however, agree so well with the Harpidae in the glabella, that a closer grouping is perhaps not quite excluded. Whittington (1950, p. 6) furthermore believes that the resemblance between the harpids and trinucleids is an example om homeomorphy, and this view is shared by the writer.

The Asaphacea and Dikelocephalacea are regarded as descendants of the Conocoryphacea, and so, too, most probably are the Calymenacea, Odontopleuracea, Lichidae, Telephidae, Cheiruracea, Phacopacea, and probably also the Raphiophoracea. In most cases the pattern of their glabellar furrows is an exaggeration of the tendencies found in the Conocoryphacea.

Superfamily *Asaphacea* Salter, 1864.[1]

In this superfamily with the Asaphidae, may the Nileidae (= Symphysuridae) safely be included, and also the Ceratopygidae (see below). The Cyclopygidae have been compared with the Nileidae, especially as they have the same type of facial sutures (Poulsen, 1927, p. 324), and may tentatively be assigned to the Asaphacea. The superfamily Asaphacea is considerably restricted in relation to Salter's section Asaphini.

The median suture across the doublure has been pointed out by several authors as characteristic of the Asaphidae. It is, however, now known that this character is not unique for this family, as claimed by Poulsen (1927, p. 322) and Reed (1930, p. 296). A median suture seems to occur in a number of Cambrian Conocoryphacean forms (cf. p. 192), and in the Ceratopygidae and the Dikelocephalacea. This feature is often neglected in the description of Cambrian trilobites, probably because it can only be observed directly in exceptional cases. The development of a median suture may, however, be detected in loose free cheeks (cf. Westergård, 1947, p. 10: "Doublure of the free cheek is truncated at the axial line". When the illustrations are as good as in *l. c.*, pl. 2, fig. 3, it may also be inferred from these). Another feature which is usually well developed in the Asaphidae is the glabellar node. This node is usually well developed in the Nileidae and Ceratopygidae, too, and is also known in the Cyclopygidae.

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[1] cf. p. 205.

In the case of the Ceratopygidae, early members show a number of features in common with early Asaphidae. The distinguishing characters are chiefly that the Ceratopygidae have 6—9 (usually 9) thoracic segments (Troedsson, 1937, p. 34), whereas the Asaphidae have 8, and the characteristic pygidium of the Ceratopygidae. Of their common features may be mentioned; median suture, glabellar node, rather large and similar hypostomes (Norwegian material of *Ceratopyge* which is being described by S. Skjeseth includes hypostomes very like that of *Niobella aurora,* figured by Westergård, 1939, pl. II). The pleural ends of the Ceratopygidae are paralleled in for example *Promegalaspides kinnekullensis* Westergård, 1939. Moreover the free cheeks and facial sutures of Ceratopygidae and early Asaphidae can hardly by distinguished. As pointed out by Whitehouse (1939, p. 245), the pre-occipital pair of glabellar furrows are typically isolated and extending more or less parallel to the axis in the Ceratopygidae. In some early Asaphidae (*e. g. Norinia regalis* Troedsson, 1937 and *Promegalaspides kinnekullensis*) a similar pattern of glabellar furrows is developed, although more diffused, as is so even in many Ceratopygidae. On the whole the cranidia of the two families may be rather similar. One may recall that a cranidium of the ceratopygid genus *Hysterolenus* Moberg, 1898 was doubtfully assigned to the Asaphidae by Stubblefield (1927, p. 137). Except for the spine in the Ceratopygidae, the pygidia of the two families agree very well. The spines of the pygidium in the Ceratopygidae are of a type that should be compared with the macropleural spines of the thorax in many trilobites (cf. the development of *Shumardia* in Stubblefield, 1926). It is therefore interesting to note that *Promegalaspides kinnekullensis* has macropleura in its last thoracic segment. In the writer's opinion the differences between the Ceratopygidae and the Asaphidae in no way exclude the possibility of a close affinity between these families. The Asaphidae may share a common origin with the Ceratopygidae, or even have developed from the apparently slightly older Ceratopygidae.

It is possible that the Conocoryphacean family Anomocaridae may not be far removed from the ancestral stock of the Asaphacea. The Anomocaridae have an asaphid-like pygidium, and well developed doublures. The glabella is of the common Conoryphacean form, not so different from that in early Asaphidae and Ceratopygidae. The pre-occipital pair of glabellar furrows in the Anomocaridae approaches in form that of the Ceratopygidae and Asaphidae (see f. inst. glabellar furrows in *Anomocare laeve,* as illustrated by Westergård, 1950, pl. 3, figs. 1—3). It is not known whether the Anomocaridae had a median suture, but their facial sutures at least converge strongly in front, indicating that if two connective sutures were developed, they must have been rather close to each other (see outline of marginal border in the cranidium of f. inst. *Anemocare laeve* figured by Westergård, 1950, pl. 3, fig. 1, and also the doublure of the free chek of *Anemocaroides limbatus,* figured *l. c.*, pl. 4, fig. 10). Whether the Asaphidae are related to the Anemocaridae or not, the Asaphidae may safely be assumed to have developed from the Conocoryphacea. Further research may solve the problem of whether they originated from the same stock as the Olenidae, Eliviniidae and possible other families with the facial sutures united in front, or not. The Dikelocephalidae may have originated from the same stock, and have often been placed near the Asaphidae, with which they were united in the same superfamily, Dikelocephalidea, by Richter (1932). The writer prefers to maintain a superfamily Dikelocephalacea as well as Asaphacea, since the relationships between the two groups are still uncertain. If the two superfamilies are again united, the name of the superfamily should be Asaphacea, if the rule of priority is applied.

Superfamily *Dikelocephalacea* Richter, 1932.

It is possible that the Illaenuridae, Kainellidae, Macropygidae, Ptychaspidae, Remopleurididae, and Richardsonellidae should be included with the Dikelocephalidae in this superfamily, named Dikelocephalidea by Richter (1932). The possible relationships between the Dikelocephalidae and Asaphidae are discussed in the preceding paragraph.

The subfamily Richardsonellinae has been assigned to the Dikelocephalidae, but this reference is doubted by Kobayashi (1935, p. 309) and Westergård (1948, p. 13). In the writer's opinion it seems best to regard the richardsonellids as constituting an independent family, the Richardsonellidae. The Dikelocephalidae and Richardsonellidae have many characters in common, such as a tendency to develop forms with expanded anterior part of the cranidium. In the Dikelocephalacea there are forms with median suture (Saukiinae), and forms with united free cheeks, leaving only an intramarginal facial suture (*Dikelocephalus*). The latter type is also known in the Richardsonellidae (*Levisella* Ulrich, 1930, cf. Rasetti, 1944, p. 246), and it seems probable that other forms like *Loganellus* Devine, 1863 had a median suture. Nevertheless, there are some circumstances suggesting that the Richardsonellidae are not so closely related to the Dikelocephalidae as usually believed. The Middle Cambrian genus *Conokephalina* Brögger, 1886 has often been assigned to the Dikelocephalidae, but is placed in the Conocoryphidae by Westergård, (1948, p. 17). A study of the type species, *Conocephalina ornatum* (Brögger, 1878), has also convinced the writer that this genus should not be assigned to the Dikelocephalidae, from which it differs markedly in the shape of the glabella and pattern of the glabellar furrows. The earliest Dikelocephalidae are thus known from the Franconian Stage (Middle Upper Cambrian). The Richardsonellidae appear to be restricted to a later stage, the late Trempealeauian. The late Middle Cambrian genus *Andrarina* Raymond, 1937 (type species *Liostracus costatus* Angelin, 1854, not *Liostracus aculeatus* Angelin, 1854, cf. Westergård, 1948, p. 13) and the probably related genus *Nericia* Westergård, 1948 were assigned to the Richardsonellinae by Westergård (1948, p. 13). *Andrarina* admittedly reminds one of *Loganellus*, but differs *i. a.* in having a small rostrum (Strand, 1929, p. 354), whereas the facial sutures meet in front axially where this feature has been studied in the Richardsonellidae. Furthermore *Andrarina* has no pits in the anterior furrow, whereas such pits are developed in all Richardsonellidae with an anterior furrow. Incidentally it may be remarked that *Andrarina,* and the probably related genus *Nericia* Westergård, 1948, both from the late Middle Cambrian of Sweden, bear resemblance to *Aphelaspis* Resser, 1942 and related genera. Excluding *Andrarina* from the Richardsonellidae, the late appearance of this family seems to exclude the possibility that the Dikelocephalidae arose from the Richardsonellidae. On the other hand, the glabella and its rather strict pattern of glabellar furrows in the Dikelocephalidae appear to be more advanced than the rather Conocoryphacean glabella in some Richardsonellidae, such as *Richardsonella* Raymond, 1924. The glabella of *Levisella* leads morphologically over to that of *Hungaia,* Walcott, 1914, which may be assigned to the Richardsonellidae. Except that it is more expanded posteriorly, as the cranidium is more expanded anteriorly, the pygidium of *Hungaia* is rather like that of *Richardsonella* (cf. Rasetti, 1944; pygidia of

Hungaia, pl. 37, figs. 3, 6—7; pygidium of *Richardsonella,* pl. 39, fig. 55). Although it appears that the Dikelocephalidae are not ancestral to the Richardsonellidae, or vice versa, it seems probable that they are related. The Richardsonellidae and allied families are here retained in the Dikelocephalacea. This is preferred to removing them to a new superfamily, especially as further studies of Cambrian forms with no rostrum may perhaps result in a closer grouping of these forms (cf. p. 192). It is possible that the Dikelocephalacea have connections with the Elvinidae and allied forms (including perhaps *Aphelaspis*), which, at least in some genera (*Elvinia* Walcott, 1924, *Taenicephalus* Ulrich & Resser, in Walcott, 1924) have a median suture, and has a tendency to develop a dikelocephalid-like glabella.

It has been suggested, with good reasons, that the Remopleurididae are descendants of the Richardsonellidae (cf. Rasetti, 1944, p. 255). *Macropyge* Stubblefield, 1927, is nearly related to *Apatokephalus* Brögger, 1896, as pointed out by Lake (1931, p. 124), and even more closely related to *Robergia* Wiman, 1905. The family Macropygidae, proposed by Kobayashi (1937, p. 479), does not seem necessary, and is here regarded as a synonym of the Remopleurididae. *Kainella* Walcott, 1925, should, in the writer's opinion, be assigned to the Richardsonellidae, making the Kainellidae a synonym. The cranidium of *Kainella* is very close to that of *Richardsonella* and *Levisella,* and its pygidium is of the same type as that found in *Richardsonella* and *Hungaia.* The Richardsonellidae and Remopleurididae form a unit, whose relationships with the Dikelocephalidae, as mentioned above, are not fully known. It may be remarked that the Richardsonellidae also remind one of the Asaphacea, having a tendency to develop a similar type of pre-occipital glabellar furrows.

The position of the Illaenuridae Raymond, 1924 is still uncertain, though it is quite possible that they are related to the Dikelocephalacea as suggested by the founder.

Superfamily *Odontopleuracea* Swinnerton, 1915.

Prantl & Pribyl (1949) assign the following families to this superfamily: Odontopleuridae (= Acidaspidae), Selenopeltididae, and Ceratocephalidae.

Two more families may possibly be related to these, though more distantly, namely the Telephidae and Lichidae.

The Telephidae are placed in a superfamily Telephaceae by Stubblefield (1950), together with the Komaspididae. If the relationships between these two families are accepted, the Telephidae no doubt had Conocoryphacean ancestors. There are all transitional forms between komaspids like *Irvingella* and more typical Conocoryphacean forms as species of *Drumaspis* (see illustrations of the family in Resser, 1942). The likeness between the Telephidae and Komaspididae is striking, but the writer is not quite convinced that it implies close affinities. The queer longitudinal glabellar furrows sometimes developed, or suggested, in *Telephus,* are not known in the Komaspididae, neither are the anterior spines. Both these characters are developed in *Glaphurus,* which, together with *Glaphurina,* is assigned to the Telephidae by Ulrich (1930). These two genera may well be related to *Telephus,* but show more Conocoryphacean characters, suggesting Conocoryphacean ancestors. On the other hand. *Glaphurus* and *Glaphurina* resemble the Odontopleuracea. Their peculiar glabellar furrows are paralleled in the Odontopleuracea, and furthermore the spinose anterior border of the cephalon, surface ornamentation, and type of thoracic segments are shared by both groups. It appears that the relationships between *Glaphurus* (and *Glaphurina*) and the Odontopleuracea can hardly be denied. It is thus probable that the Odontopleuracea, too, have developed from the Conocoryphacea. This has already been suggested by Poulsen (1927, p. 328), partly because the Odontopleuracea have a rostral plate that appears to be a modified Conocoryphacean type, and partly because of similarities between *Acidaspis* and *Pharostoma,* the latter being regarded by Poulsen (1927, p. 327) as a member of the Calymenidae, which he accepts as descendants of the Conocoryphacea.

The Lichidae have often been put together with the Odontopleuridae in classification. Warburg (1925, p. 71) discusses the similarities between these families, and concludes that it is difficult to say whether they prove close relationships, but that it seems probable, although these two families are rather specialized in many other features. Poulsen (1927, p. 327), too, discusses the resemblance between the Odontopleuridae and Lichidae, and believes that they probably came from a common ancestor, though the specialization of these two types began at an early period. Prantl & Pribyl (1949, p. 132) on the other hand wish to mention the fact that the similarities may be explained in some other way, particularly by a convergence brought about by a similar mode of life. The writer agrees, however, with Swinnerton (1915, p. 544), who considers that "the usual stability of the glabella in other families and suborders emphasizes the genetic and classificatory value of the strong tendency towards the breaking up of the glabella into separate lobes shown in these two families". The writer is inclined to believe that the Lichidae may yet be shown to have affinities with the Odontopleuracea. Till the phylogenetic relationships of the Lichidae are better understood, they may, if it is felt necessary, be assigned to a superfamily Lichacea, as proposed by Kobayashi (1935, p. 83) and Phleger (1936).

Pharostoma is an interesting genus apparently akin to the Odontopleuracea, as well as to other groups of trilobites. It has usually been placed in the Calymenidae (f. inst. by Warburg, 1925, p. 68; Poulsen, 1927, p. 326; Öpik, 1937, p. 22, Thorslund, 1940, p. 144), but Shirley (1936, p. 396) doubts the justification for this, and remarks further (*l. c.*, p. 386) that "in those characters *Pharostoma* differs from the Calymenidae, it seems to approach the Odontopleuridæ". The glabella of *Pharostoma* (see f. inst. Öpik, 1937, pl. XVI) shares a number of characters with that of Odontopleuracea. Furthermore its free cheeks (see Thorslund, 1940, pl. II, fig. 4) and those of the Odontopleuracea agree remarkably well. The pygidium of *Pharostoma* appears, however, less advanced. This, and the lack of any pre-glabellar field in the Odontopleuracea, does not affect the writer's opinion that *Pharostoma* is most probably related to the Odontopleuracea, and is, at least morphologically, a transitional form between these and the Conocoryphacea. *Glaphurus,* apparently related to the Odontopleuracea (see above) may also be compared with *Pharostoma,* which, however, has a less advanced character of the glabella. *Pharostoma* shows so many features in common with the Calymenacea as well, that the writer is inclined to believe that it denotes affinities. One may compare for example *Pharostoma similis* as illustrated by Thorslund (1940, pl. II, figs. 1—14) with illustrations of *Flaxicalymene jemtlandica* (*l. c.,* pl. III, figs. 19—22). Nevertheless, the writes agrees with Shirley (1936) that *Pharostoma* should probably not be placed in the family Calymenidae (nor Homalonitidae). It most likely represents an evolutionary lineage between those of the Odontopleuracea and Calymenacea.

Superfamily *Calymenacea* Swinnerton, 1915.

Even if *Pharostoma* (discussed in the preceding paragraph) is not recognized as being related to the Calymenacea, there can be little doubt that the latter were derived from the Conocoryphacea, as maintained by Shirley (1936, p. 396).

Euloma ornatum Angelin, 1854 is a Tremadocian species which, at least morphologically, holds an intermediate position between the Calymenacea and Conocoryphacea. It has a glabella of the calymenid type, and a thorax similar to that of *Ptychoparia,* which is also known in the calymenids. The pygidium recalls that of the calymenids, although it is rather short in comparison to its width. *Euloma ornatum* has a marginal border in front of the pre-glabellar field, such as is also known in an early calymenid, *Synhomalonotus murchisoni* (Salter) from the Arenigian of Shropshire (see Shirley, 1931, pl. 1, figs. 5—6). The test of *Euloma ornatum* as shown in Norwegian material, is very finely granulated. Were it not for the typical opisthoparian facial sutures and strong genal spine of the free cheeks, *Euloma ornatum* might have been assigned to the Calymenidae. It is here retained in the Conocoryphacea, although its family affinities are uncertain. *Euloma* has often been assigned to the Olenidae, although its founder, Angelin (1854, p. 61) includes it in the Aulacopleuridae. The type species of *Euloma, E. laeve* Angelin, 1854, is unfortunately incompletely known, and it is not even known for certain that it is congeneric with *E. ornatum.* The latter species belongs neither to the Olenidae nor the Aulacopleuridae. If *E. ornatum* and *E. laeve* are congeneric, *Euloma* should be assigned to another, possibly new, Conocoryphacean family. It may be that this family, too, is rather close to the ancestors of the Odontopleuracea and allied forms, including *Pharostoma.*

Superfamily *Raphiophoracea* (Salter, 1864) new name.

Salter (1864) erected a section Ampycini, but since its type family Ampyxidae Chapman, 1890 is considered a synonym of Raphiophoridae Angelin, 1854, the name of the superfamily is changed to Raphiophoracea. The following families may be assigned to it: Dionideidae, Endymionidae, Raphiophoridae, and Trinucleidae.

It appears probable that the Raphiophoracea have developed from the Conocoryphacea rather than the Zacanthoidacea, or any other superfamily. Evidence in favour of this view is *i. a.* the type of pleurae, which is common in the Conocoryphacea, but apparently not known in the Zacanthoidacea, and the resemblance of the Raphiophoracea to Conocoryphacean families, as the Harpidae. Lake (1907, p. 45) includes *Orometopus* Brögger, 1896 in the Trinucleidae, thus claiming opisthoparian ancestors for the later Trinucleidae. The writer wholeheartedly accepts the inclusion of *Orometopus* in the Raphiophoracea, but it is doubtful whether it should be assigned to the Trinucleidae (or any of the other families recognized). The Raphiophoridae also are here considered to have an opisthoparian suture (cf. Stubblefield, 1936, p. 419).

Superfamily *Phacopacea* Salter, 1864.[1]

Richter (1932) assigns the Phacopidae, Cheiruridae, and Encrinuridae to this superfamily. However, Warburg (1925, p. 77) maintains that "the Phacopidae differ in most characters rather much from the Cheiruridae and the Encrinuridae, and, if they came from the same ancestral stock, they must have separated at a very early stage". Öpik (1937, p. 93) restricts the Phacopacea to the family Phacopidae, and erects a new superfamily for the excluded families;

Superfamily *Cheiruracea* Öpik, 1937.

Öpik assigns the Cheiruridae, Encrinuridae, and Pliomeridae (the latter being given family rank) to this superfamily. The generic relationships of these families and of the Phacopidae to other families are still not understood, though Öpik (1937, pp. 75, 93) discusses several Cambrian genera as possible ancestors. The writer is inclined to believe that the superfamilies Phacopacea and Cheiruracea probably can not be traced very far back, perhaps only to the late Cambrian. In any case, they are most probably descendants of the Cococoryphacea. Evidence in favour of this view is; development of proparian sutures known with certainty only in the Conocoryphacea (and Agnostacea); development of facial sutures united in front only known in the Conocoryphacea and their descendants; type of thoracic segments agreeing best with those of the Conocoryphacea. The types of glabellae and glabellar furrows developed in the Phacopacea and

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[1] cf. p. 205.

Cheiruracea need not necessarily be considered as having developed from the Conocoryphacea, but it does appear to be quite possible. The differences between the Phacopidae and Paradoxididae are so great that the resemblance in their hypostomes and glabellae, pointed out by Raw (1925, p. 284) (and which in the writer's opinion are not too definite), should be ascribed to morphological convergence and gives no reason for closely associating these forms.

Notes on the Names of Superfamilies and Families.

Lacking any rules in selecting names of superfamilies, the writer as a rule follows the procedures of R. & E. Richter (1941, p. 15) and Arkell (1950, p. 358).

When the name of a superfamily (or family) is changed because the name of its type family (resp.: type genus) is changed, the name of the author of the taxonomic grouping may be retained in brackets, followed by the name of the author who made the nomenclatorial alteration (R. & E. Richter, 1941, p. 15). For example, Walcott (1891) erected the Mesonacida. Since Mesonacidae was later regarded as an invalid synonym of Olenellidae, R. & E. Richter (1941) changed the name of the superfamily to Olenellidae. The superfamily may then be referred to as Olenellidea (Walcott, 1891) R. & E. Richter, 1941, or rather (see below) Olenellacea (Walcott, 1891) R. & E. Richter, 1941. It is not necessary to add the name of an author who has merely changed the termination of a superfamily (or family). Whereas families automatically take the termination -idae (Article 4 of the Rules), there are at present no rules for the suffixes of superfamilies. Both the terminations -idea and -acea (-aceae) have been used for trilobite superfamilies. The writer has preferred to retain one only, and has chosen -acea, because this termination is now commonly used for superfamilies in different classes of animals, and because -idea resembles -idae too much.

There are also no rules concerning the name to be adopted when two or more superfamilies are united. By analogy with the rules for genera and species, the rule of priority has been applied here. According to Bull. Zool. Nomen. (1950, pp. 329—330), generic and specific names published in the same work at the same time shall be assigned priority on the basis of precedence in pages, lines, and position in lines, and the same is here applied to superfamilies.

According to R. & E. Richter (1941, p. 16) the superfamily Agnostacea (*olim* Agnostidea) is attributed to Salter (1864), who erected a section Agnostini, and thus for the first time allowed the agnostids a higher taxonomic rank than family. Provided the groupings proposed by an author are of higher order than family, they need not have been called superfamilies by him (Arkell, 1950, p. 358). Following this principle, three other superfamilies should then also be attributed to Salter (1864), their type families being those of the three additional sections erected by him, namely Phacopini, Asaphini, and Ampycini. Since Ampyxidae Chapman, 1890 is considered a synonym of Raphiophoridae Angelin, 1854, the name of this superfamily is changed to Raphiophoracea.

According to R. & E. Richter (1941, p. 15) families and subfamilies may be regarded as co-ordinate, from a nomenclatorial standpoint, in analogy with genera and subgenera. It follows from this that a family and its typical subfamily shall be attributed to the same author. This is, of course, regardless of the fact whether a subfamily is later given family rank, or a family is later split into two or more subfamilies.

List of Families, Arranged in Superfamilies.

No doubt many of the families listed below (especially of the Conocoryphacea) will later be found to be synonymous with others, and should at the most be regarded as subfamilies.

Not all trilobite families are listed below. Some are probably missing because the writer has not been aware of their erection. Others are missing because they are imperfectly known, or too smooth-surfaced to disclose affinities with other families for the time being, such as; Bathyuridae Miller, 1889, Cephalocoeliidae Raymond, 1937, Holotrachelidae Warburg, 1925, Isocolidae Angelin, 1854, Ityophoridae Warburg, 1925, Punctulariidae Raymond, 1937, Taihungshaniidae Sun, 1931, and Tsinaniidae Kobayashi, 1935.

Zacanthoidacea Richter, 1932 (Syns. Bathyuriscidea Richter, 1932, Corynexochidea Kobayashi, 1935 — R. & E. Richter, 1948).
  Bathyuriscidae Richter, 1932 (prob. syn. for Corynexochidae).
  Corynexochidae Richter, 1932.
  Dorypygidae Kobayashi, 1935.
  Illaenidae Corda, 1847.

Kooteniidae Resser, 1939 (prob. syn. for Dorypygidae).
? Lancastriidae Kobayashi, 1935 (prob. syn. for Oryctocephalidae).
? Oryctocephalidae Beecher, 1897.
Ptarmiganiidae Resser, 1935 (prob. syn. for Corynexochidae).
Scutellidae (Corda, 1847) R. & E. Richter, 1925 (= Eobronteidae Sinclair, 1949).[1]
Styginidae Vogdes, 1893.
Zacanthoididae Swinnerton, 1915.

Agnostacea Salter, 1864 (syn. Eodiscidea Richter, 1932).

Agnostidae (Corda, 1847) Salter, 1864 (syns., see Westergård, 1936).
Eodiscidae (Coquin, 1896) Raymond, 1913.

Olenellacea (Swinnerton, 1915) R. & E. Richter, 1941.

Olenellidae (Walcott, 1891) Vogdes, 1893.

Redlichiacea Richter, 1932 (prob. syn. Ellipsocephalidea Richter, 1932).

Ellipsocephalidae Matthew, 1887.
Olenopsididae Kobayashi, 1935 (prob. syn. for Redlichiidae).
Paradoxididae Emmrich, 1839.
Protolenidae R. & E. Richter, 1948 (prob. syn. for Ellipsocephalidae).
Redlichiidae Poulsen, 1927.

Conocoryphacea Swinnerton, 1915 (prob. syns. ?Burlingiidea Richter, 1932, Harpedacea Kobayashi, 1935, Norwoodiidea Richter, 1932, Olenidea Swinnerton, 1915 — R. & E. Richter, 1941, Proetacea Kobayashi, 1935, Ptychopariidea Richter, 1932).

Agraulidae Howell, 1937.
Alokistocaridae Resser, 1939.
Andrarinidae Raymond, 1937.
Anomocaridae Poulsen, 1927.
Asaphiscidae Raymond, 1924.
Blountiidae Lochman, 1944.
? Burlingiidae Walcott, 1908.
Burnetiidae Resser, 1942.
Cedariidae Raymond, 1937.
Conocoryphidae Angelin, 1854.
Crepicephalidae Kobayashi, 1935.
Damesellidae Kobayashi, 1935.

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[1] The name Eobronteidae was proposed for this family because Scutellidae is well established as a name for a family of echinoids. There are, however, at present no rules concerning homonymy in families.

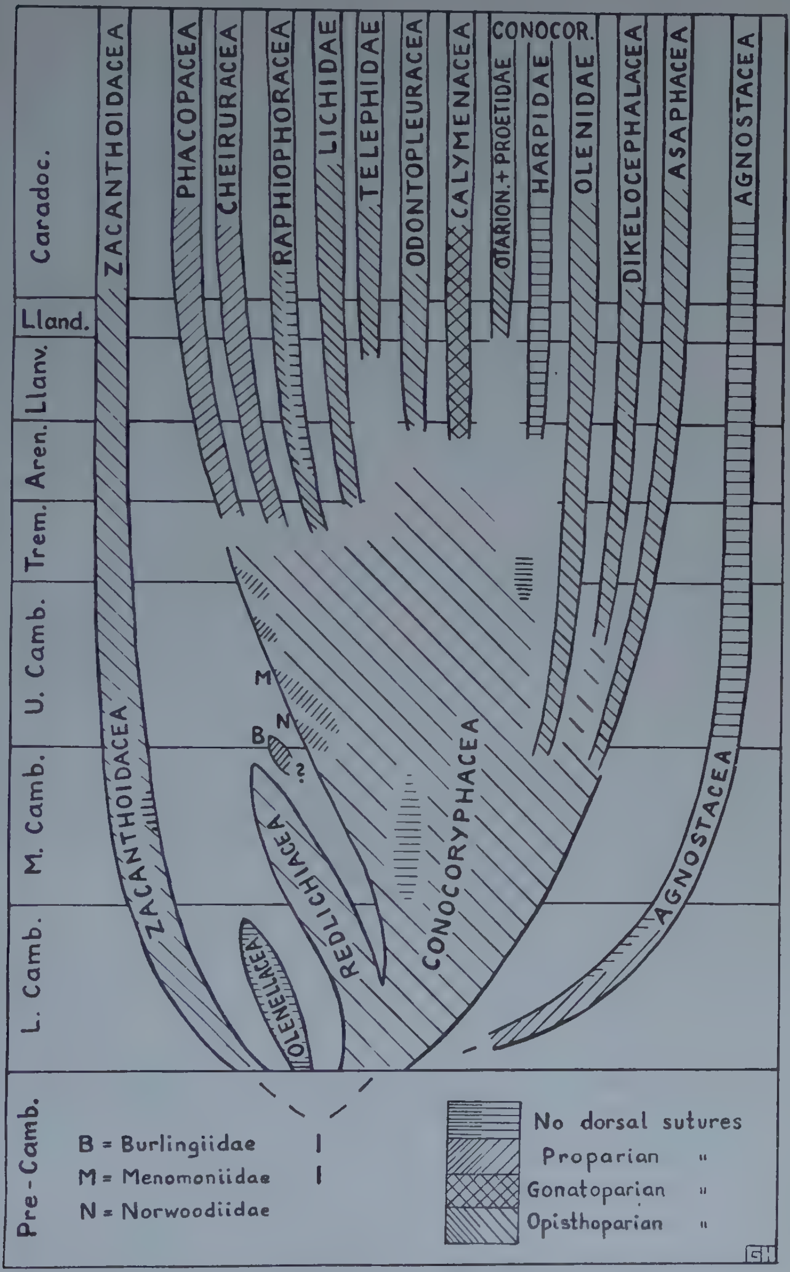

Fig. 2. Illustration of the supposed relationships of the major groups of trilobites.

Elviniidae Kobayashi, 1935.
Emmrichellidae Kobayashi, 1935.
? Entomaspididae Ulrich, 1930.
Harpidae Corda, 1847.
Harpididae Whittington, 1950 (c).
Komaspididae Kobayashi, 1935.
Lejostegidae Bradley, 1925.
Liostracidae Angelin, 1854
Llanoaspididae Lochman, 1944.
Lloydiidae Kobayashi, 1935.
Marjumiidae Kobayashi, 1935.
Menomoniidae Walcott, 1916.
Nereidae Whitehouse, 1939.
Norwoodiidae Walcott, 1916.
Olenidae Burmeister, 1843.
Otarionidae (Salter, 1864) R. & E. Richter, 1926.
Pagodiidae Kobayashi, 1935.
Plethopeltidae Raymond, 1924.
Proetidae Salter, 1864.
Ptychopariidae Matthew, 1887 (prob. syn. for Conocoryphidae).
? Shumardiidae Lake, 1907.
Solenopleuridae Angelin, 1854.
Tollaspididae Kobayashi, 1943.
Triarthridae Ulrich, 1930 (syn. for Olenidae).

Asaphacea Salter, 1864.

Asaphidae Burmeister, 1843.
Ceratopygidae Raymond, 1927.
? Cyclopygidae (Pictet, 1854) Raymond, 1925.
Nileidae Angelin, 1854.
Symphysuridae Poulsen, 1927 (syn. for Nileidae).

Dikelocephalacea Richter, 1932.

Dikelocephalidae Miller, 1889.
? Illaenuridae Raymond, 1924.
? Kainellidae Ulrich & Resser, 1930 (prob. syn. for Richardsonellidae).
? Macropygidae Kobayashi, 1937 (prob. syn. for Remopleurididae).
? Ptychaspidae Raymond, 1924.
? Remopleurididae Corda, 1847.
? Richardsonellidae Raymond, 1924.

Calymenacea Swinnerton, 1915.

Calymenidae Edwards, 1840.
Homalonotidae Chapman, 1890.

Odontopleuracea Swinnerton, 1915.

- Ceratocephalidae R. & E. Richter, 1925.
- Odontopleuridae Burmeister, 1843.
- Selenopeltididae Corda, 1847.

? Telephidae Angelin, 1854 (Telephidaceae Stubblefield, 1950).

? Lichidae Corda, 1847 (Lichacea Kobayashi, 1935).

Raphiophoridacea (Salter, 1864) new name (syns. Trinucleacea Swinnerton, 1915 — Kobayashi, 1935, Cryptolithidea Richter, 1932).

- Ampycidae Chapman, 1890 (syn. for Raphiophoridae).
- Cryptolithidae Angelin, 1854 (syn. for Trinucleidae).
- Dionididae Raymond, 1920.
- Endymionidae Raymond, 1920.
- Raphiophoridae Angelin, 1854.
- Trinucleidae Emmrich, 1844.

Cheiruracea Öpik, 1937.

- Cheiruridae Corda, 1847.
- Cybelidae Holliday, 1942 (prob. syn. for Encrinuridae).
- Encrinuridae Angelin, 1854.
- Pliomeridae Raymond, 1913.

Phacopacea Salter, 1864.

- Phacopidae Corda, 1847.

Concluding Remarks.

The classification adopted here is in no way meant to be definite, but merely a suggestion for a handy grouping at the present state of knowledge. The table (Fig. 2) clearly shows where the most work remains to be done.

One of the aims of these remarks on the classification of trilobites has been to show that the early trilobites are closely related to each other, (as suggested in fig. 2), often to such a degree that it is difficult to find any definite distinctions between the early groups. It is unnecessary to imagine "that the trilobites had diverged into a number of separate groups before the habit of strengthening the dorsum with lime developed", as proposed by Whitehouse (1939, p. 180) and supported by Rasetti (1948).

The fact that there is a greater number of post-Cambrian superfamilies than Cambrian is, to a certain extent, probably owing to a better knowledge of the post-Cambrian trilobites, and to their being easier to distinguish. There are, however, different trends among the Cambrian Conocoryphacea, but it appears to be best to assign them all to one superfamily for the time being. When the different trends have been worked out, this superfamily will perhaps be split up again. Even so, the trilobites appear to have specialized along more different lines in Ordovician time (at least with regards to their glabella), justifying the recognition of a greater number of post-Cambrian superfamilies. As pointed out by Kobayashi (1925, p. 83), several new lines of trilobite evolution were initiated at the beginning of Ordovician time.

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SUB-SOLIDUS DIAGRAM OF PYROXENES FROM COMMON MAFIC MAGMAS

BY

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The crystallization relations of the usual rock-making pyroxenes have been the subject of numerous discussions for many decades. The known facts, from natural rocks and synthetic melts, have been summarized and systematically discussed by Hess (1941). In the present paper the principal features of the sub-solidus relations will be described, but a detailed examination is impossible from lack of factual knowledge.

The simplified chemical composition of the system under consideration can be expressed in terms of three "molecules": $MgSiO_3$—$FeSiO_3$—$CaSiO_3$ with the symbols En, Fs, Wo, respectively. Auxiliary symbols are Di and He for $CaMgSi_2O_6$ and $CaFeSi_2O_6$ respectively.

The melting relations in this system including the reaction relations between olivine and various pyroxenes have been adequately determined (See Bowen, Schairer, Posnjak 1933; Bowen and Schairer 1935; Osborn 1943, where further literature references are given). The sub-solidus relations, on the other hand, are inadequately known, the only pertinent experimental information being, that in the system $MgSiO_3$—$FeSiO_3$ the high-temperature mixed crystals (pigeonites of natural rocks) invert to low-temperature orthopyroxenes between 1140° C for pure $MgSiO_3$ and 960° C for almost pure $FeSiO_3$. See Bowen, Schairer and Posnjak 1933. At elevated temperatures the pigeonites form with the Di—He series (= augites of natural rocks) complete solid solutions (= clinopyroxenes) extending over the whole area En — Fs — Di — He (except in very ironrich mixtures). But the orthopyroxenes take little lime in solid solution and are in the ternary diagram limited to a narrow field close to the En—Fs join. If we think of the ternary diagram with temperature axes erected perpendicular to the plane of the diagram, then the clinopyroxene field extends like an arched ceiling over the diagram while the orthopyroxene series forms one of the side walls: See Fig. 1. At temperatures below the "ceiling" two pyroxene phases coexist the composition of which varies with the temperature. It is evident that orthopyroxenes inverted from the monoclinic phase must have crystallized at temperatures above the plane B—B′—C—C′, whereas primary orthopyroxenes must have crystallized below this plane.

The course of crystallization may now be adumbrated as follows: In most magmas crystallization will start below the inversion plane B—B′—C—C′ with separation of two phases (which in natural rocks correspond to Mg-rich augite and Mg-rich orthopyroxene). As the residual liquid is pushed towards the Fe-rich fields of the diagram, it will come closer to the inversion plane, for the inversion temperature decreases with increasing iron, eventually the liquid may reach the plane and two clinopyroxene phases separate (corresponding to rocks containing pigeonite and augite).

Eventually the residual iron-rich liquid may go beyond and above the "ceiling"; from then on only one (monoclinic) pyroxene phase will separate. This field can only be reached after extreme fractional crystallization so examples to study are few. In a recent letter Hess says that augite apparently continues to crystallize, but pigeonite disappears as a phase; but whether or not this disappearance is related to the appearance of some other phase such as fayalitic olivine or ferrohornblende is as yet undetermined. The experimental diagram $CaFeSi_2O_6$—$FeSiO_3$, as determined by Bowen, Schairer and Posnjak (1933), is very complicated (not shown in Fig. 1) and indicates that iron-rich pigeonites are unstable and break up into tridymite and olivines. But what happens in this part of the diagram is not very mportant petrologically, for natural rocks hardly ever contain so much iron.

In conclusion it may be said that Fig. 1, although intensionally simplified and subject to modificaton in details as new facts become known, still, as it stands, corresponds to the leading experimental facts, and to the observed course of crystallization in pyroxenes from common mafic magmas. See Fig. 2.

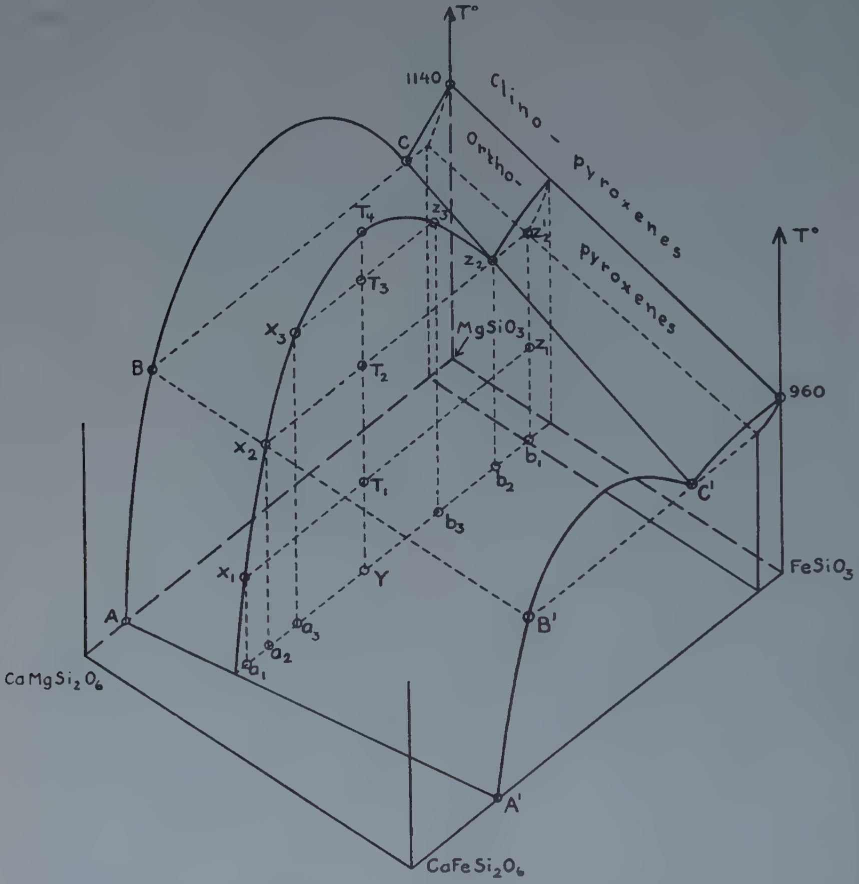

Fig. 1. Schematic equilibrium diagram of the orthopyroxenes and clinopyroxenes at sub.-solidus temperature. The vertical plane $MgSiO_3$, $FeSiO_3$, 1140, 960 corresponds to the diagram published by Bowen and Schairer (1935), but it is here simplified and the complications due to the breaking up of pure $FeSiO_3$ have been omitted. The curve A′—B′—C′—960 in the vertical plane rising from $FeSiO_3$ — $CaFeSiO_6$ demonstrates the approximate, inferred sub-solidus equilibrium relations in the system of (nearly) pure ferrosilite-hedenbergite. The curve A—B—C—1140 in the plane rising from $MgSiO_3$ — $CaMgSi_2O_6$ gives the simplified, inferred sub-solidus equilibrium diagram of the system enstatite-diopsde. Above the domed surface A—A′—B—B′—C—C′ (the "ceiling") clinopyroxenes are stable. In the region below the ceiling and above the plane B—B′—C—C′ (in the "attic") two clinopyroxenes co-exist (in natural rocks they correspond to augite and pigeonite), and below the plane B—B′—C—C′ clinopyroxene is in stable equilibrium with orthopyroxene.

A homogeneous clinopyroxene at temperature T_4 and composition given by Y will, upon cooling to T_3, break up into two pyroxenes x_3 and z_3 (com-

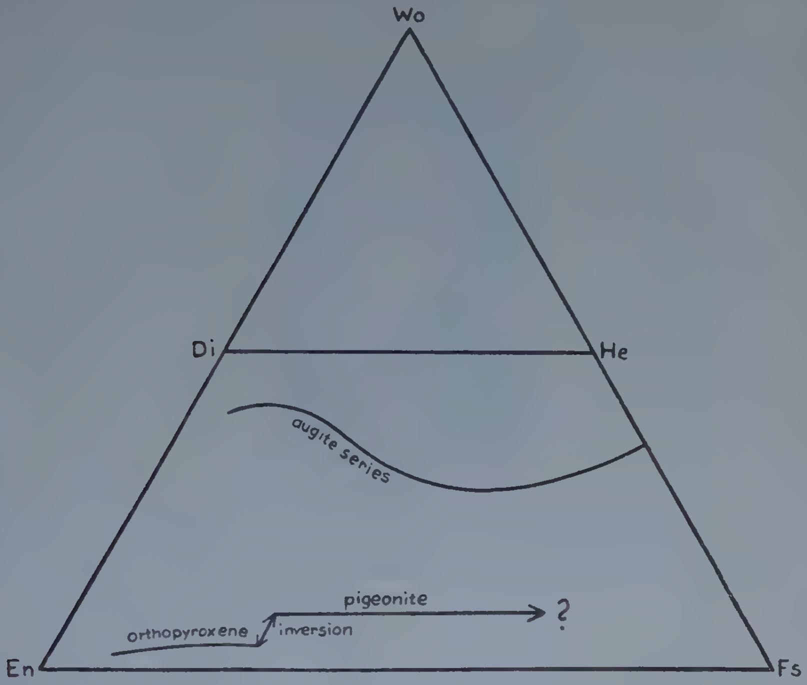

Fig. 2. Normal crystallization course in pyroxenes. The diagram corresponds to that published by Hess in 1941 with the amendments suggested by him in a letter of December 1950. It reflects the sub-solidus relations illustrated in Fig. 1.

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position given by a_3 and b_3 respectively). On further cooling to T_2 the co-existing phases are x_2 and z_2 (composition a_2 and b_2). But this temperature is also the point of inversion of the Ca-poor clinopyroxene z_2 into the orthorombic pyroxene z_2'. Observe that the inversion temperature of any one of the clinopyroxenes is **below** the inversion temperature of the corresponding Ca-free pyroxene of the same Mg/Fe-ratio. Below this temperature, for example at T_1, clinopyroxene x_1 (composition a_1) exists in equilibrium with orthopyroxene z_1 (composition b_1).

CARL WILHELM CARSTENS

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AV HARALD BJØRLYKKE

Verksgeolog dr. philos. Carl Wilhelm Carstens som har vært medlem av vår forening siden 1911, døde plutselig den 5. juli i år. Han var født i Trondheim i 1887 og ble således bare 63 år gammel. Carstens vokste opp i et bergmannsmiljø idet hans far også var bergutdannet og cand. min. fra Universitetet i 1864. Etter å ha tatt artium i 1906 begynte han sine studier ved universitetet og ble uteksaminert cand. min. i 1911 med de beste karakterer i sitt kull.

Helt fra begynnelsen av studietiden viste Carstens særlig interesse for mineralogi og geologi og hans første geologiske publikasjon ble trykt i N. G. U.'s årbok for 1911, samme år som han tok avgangseksamen.

Dette arbeid omfatter kartlegging og beskrivelse av 3 forskjellige felter i Mo herred i Nordland og feltarbeidet ble utført sommeren 1910 mens han ennå var student. Man merker allerede i dette arbeid hans særlige interesse for malmgeologi.

Hans neste publikasjon omhandler teoretiske betraktninger over krystallisasjonsfølgen i et kismagma og ble trykt i Norsk geologisk tidsskrift i 1914. Dette arbeid er hans første publikasjon om kisproblemene som kom til å bli hans hovedinteresse gjennom hele livet og han har her gjort sin største insats som geolog. Carstens holder seg i dette arbeid fremdeles til Brøgger og J. H. L. Vogts teori om kisstokkenes eruptive natur, men sier i innledningen: »Våre kisforekomster synes således både hvad optreden og genesis angår å være blit underkastet en meget nøie undersøkelse. Men enkelte spørsmål er ennu ubesvart, således f. eks. den såkaldte saussuritisering i forhold til kisstokkenes størrelse og beliggenhet, bergartenes og kisstokkenes forskjelligartede metamorfose etc. Jeg forbeholder mig ved en senere anledning når mit materiale fra en rekke Trondhjemske kisgruber er blit komplettert å komme tilbake til de her nevnte spørsmål.«

I 1912 ble Carstens ansatt som assistent ved geologisk institutt i Trondheim hos professor J. H. L. Vogt. I 1915 mottok han fra Norges tekniske høgskoles fond et bidrag til undersøkelse av peridotittfeltene på Hestmannøy og omgivende øyer. Dette arbeid ble utvidet til å omfatte de fleste norske peridotittfelter. Våren 1916 oppholdt Carstens seg ved Geologisk institutt i Oslo for å bearbeide det innsamlete materiale. Han fikk samme år oppdrag fra Norges geologiske undersøkelse å revidere det geologiske rektangelblad Trondheim.

Det er ikke mulig ved denne anledning å omtale alle Carstens arbeider som omfatter tilsammen 83 publikasjoner. De gir et godt inntrykk av hans store allsidighet. De fleste omhandler kisforekomstene som ble hans hovedoppgave gjennom hele livet, men man finner arbeider over de fleste områder av geologien. Hans kjærlighet til mineralogien holdt seg hele livet og hans mineralogiske arbeider omfatter beskrivelser av en rekke forskjellige mineraler fra slagg- og sementmineraler, ertsmineraler og vanlige bergartsdannende silikater.

I 1920 ble Carstens utnevnt til dosent i krystallografi, mineralogi og petrografi ved Norges tekniske høgskole, en stilling som han hadde inntil 1937, da han gikk helt over til malmgeologisk arbeid og ble ansatt som verksgeolog ved Løkken gruve. Samtidig var han også konsulent ved flere andre norske gruver og bedrifter.

Carstens var en glimrende lærer, av den type som studentene beundret og husket for resten av livet. Også etter at han var sluttet ved høgskolen viste han stor interesse for bergstudentene. Han fungerte hvert år som sensor og fulgte interessert med i studentenes arbeid også etter at de var ferdige med høgskolen. Gjennom en lang årrekke utførte Carstens geologiske feltarbeider i Trondheimsfeltet som medarbeider i Norges geologiske undersøkelse, og han publiserte en rekke arbeider over Trondheimsfeltet og dets kisforekomster. Det første store arbeid over dette var »Oversikt over Trondhjemsfeltets bergbygning« som ble trykt i 1920. Han gir her den første samlete oversikt over kisforekomstene og inndeler dem etter sin dannelse og opptreden i 6 grupper: A. Rørostypen, B. Skjækerdalstypen, C. Lillefjelltypen, D. Rødhammertypen, E. Leksdalstypen og F. Impregnasjonstypen. I senere arbeider reduserer han antall kistyper til 4 nemlig: 1. Leksdalstypen, 2. Rørostypen, 3. Rødhammertypen og 4. Fløttumtypen.

I 1923 oppholdt Carstens seg i Zürich hos professor Niggli hvor han utførte mineralogisk-petrografiske undersøkelser av de ordovisiske lavaer i Trondheimsfeltet. Han tok her sin doktorgrad på arbeidet: »Der Unterordovisische Vulkanhorisont in dem Trondhjemsgebiet. Mit besonderer Berücksichtigung der in ihm auftretenden Kiesvorkommen.« Dette arbeid gir en utførlig behandling av kisforekomstene av Leksdalstypen som opptrer som lag mellom lagene av grønnsteinslava. Carstens forklarer disse kisdannelser som marine sedimenter som vesentlig er dannet biokjemisk og forårsaket av den vulkanske virksomhet.

Carsten's teori om den sedimentære dannelse av kis av Leksdaltypen ble tidlig alminnelig anerkjent. Om dannelsen av de andre typer av kismalmer har det imidlertid hersket noe forskjellige oppfatninger blant norske geologer. I et arbeid i Zeitschrift für Praktische Geologie i 1932: »Zur Frage der Genesis der Norwegischen Kiesvorkommen«, hevder Carstens en hydrotermalmetasomatisk dannelse av alle de epigenetiske norske svovelkisforekomster og mener at de er dannet av sulfidoppløsninger fra et felles stammagma. Den forskjelige kjemiske karakter av de forskjellige kistyper forklarer han dels som en funksjon av magmanær eller magmafjern dannelse og dels ved deres forhold til de forskjellige eruptivbergarter. Således anser han den eldre type Rørostypen knyttet til gabbrobergarter og den yngre type Rødhammertypen knyttet til trondheimitter. Denne oppfatning av kisenes genesis har han funnet videre støtte for ved senere feltarbeider. En meget viktig støtte for sin teori fant han i en pillowstruktur i en del av kisen på Løkken og som tydet på en metasomatisk dannelse av denne.

I de siste 15 år arbeidet Carstens også meget med kisforekomstenes geokjemi og fant ved spektrografiske analyser videre støtte for sin oppfatning av kisenes genesis.

Carstens nedla også et stort arbeid på studiet av våre titan- og vanadiumholdige jernmalmer. I 1938 reiste han en tur til India som konsulent for Christiania Spigerverk for å befare en vanadiumførende jernmalmforekomst der.

Han har også utført omfattende undersøkelser over norske forekomster av nikkel-, molybden-, mangan- og gullmalmer over hele landet.

Mange av Carsten's publikasjoner fra de senere år var delvis bygget på materiale fra hans arbeid som konsulent for private bedrifter. Uten hans utpreget vitenskapelige innstilling ville dette sikkert ikke blitt publisert og kommet vitenskapen til nytte. Selv under arbeid med rent praktiske oppgaver forsømte han aldri å legge arbeidet slik an at han samtidig fikk materiale av vitenskapelig interesse. Under sitt samarbeid med praktiske bedrifter var han en utrettelig forkjemper for den vitenskapelige forskning som et nødvendig grunnlag for de praktiske bedrifters virksomhet.

Foruten sine trykte arbeider har Carstens skrevet mange upubliserte rapporter over undersøkelser av forekomster av malm og mineralske råstoffer fra alle deler av landet. Hans rapporter var alltid meget omhyggelig utarbeidet og vitenskapelig nøkterne i sine konklusjoner. Til tross for sin store erfaring i alle typer av forekomster lot han seg aldri forlede til å uttale seg uten å gjøre alle mulige observasjoner, hans rapporter inneholder derfor mange observasjoner av rent vitenskapelig interesse.

Fra 1936 var Carstens bestyrer av mineralsamlingen ved Det Kgl. Norske Videnskabers Selskabs Museum i Trondheim. Med økonomisk støtte fra bergindustrien bygget han her opp en glimrende utstillingssamling hvor også den praktiske geologi var utmerket representert.

Carstens foretok mange studiereiser til utlandet, til Cornwall i 1913, til Italia i 1922 hvor han blant annet besøkte Vesuv og til Finnland i 1925. I 1929 reiste han i Tyskland hvor han besøkte kisforekomstene ved Meggen og i 1931 studerte han svovelforekomstene på Sisilia. De store spanske kisforekomster i Huelva besøkte han i 1933. Under disse reiser innsamlet han meget vitenskapelig verdifullt materiale fra utenlanske malmforekomster for det geologiske institutts samlinger ved høgskolen.

På grunn av sine allsidige kunnskaper ble Carstens meget benyttet i offentlige oppdrag og komiteer.

I 1933 ble han oppnevnt som medlem av den rådgivende komité for malmletingen og fra 1942 var han formann i malmletingskomiteen. Han var formann i statens bergkommisjon fra 1945 og medlem av komiteen for statens berginteresser fra 1948. Han var også medlem av det geologiske utvalg som ble oppnevnt av Norges teknisk-naturvitenskapelige forskningsråd i 1947. Han var medlem av Det Kgl. Norske Videnskabers Selskab fra 1926 og medlem av vitenskapsakademiet i Oslo fra 1933.

I 1948 holdt Carstens etter anmodning en serie forelesninger over malmgeologi ved universitetet.

Han hadde en usedvanlig arbeidskraft. Til tross for sine mange arbeidsfelter fikk han tid til å følge med i alle grener av geologien og publisere vitenskapelige avhandlinger over mange forskjellige emner. Under sine stadige reiser rundt omkring i landet ble han kjent med Norges geologi som kanskje ingen annen, og han var en kjær gjest ved alle våre gruver hvor han blant ingeniørene traff igjen sine gamle elever fra høgskolen.

I sine siste år var Carstens vesentlig opptatt med geologiske undersøkelser av Løkkenfeltet hvor han hadde ledet de geologiske og geofysiske malmletingsarbeider i mange år. Den store sammenfattende beskrivelse av dette felt rakk han dessverre ikke å få ferdig.

Overfor kolleger var Carstens alltid hjelpsom med råd og dåd og særlig hadde han omsorg for de unge bergingeniører og geologer. Han var ikke bare fagmenneske men la også stor vekt på studentenes rent menneskelige utvikling. I 1914 tok han initiativet til dannelsen av bergstuderendes forening i Trondheim, og var en drivende kraft i denne forening helt til sin død. Denne forening nød også godt av Carstens enestående evner som kåsør og festtaler. På grunlag av gamle bergtradisjoner utarbeidet han et festlig serimoniell og fikk innført festdrakter som var kopier av gamle bergingeniøruniformer. For sine store fortjenester i denne forening ble han utnevnt til kommandør av Lapis Nidarosiensis, en utmerkelse som hittil bare har vært tildelt to andre bergingeniører nemlig bergmester Bachke og ingeniør V. N. Hybinette. Fra 1920 var han stormester i ordenskapitlet. Hans festlige taler ved høytidelige anledninger i denne forening vil minnes av bergingeniører over hele landet.

I to perioder fra 1933—34 og 1946—47 var Carstens også formann i bergingeniørenes avdeling av Norsk Ingeniørforening.

Til tross for sine nøkterne faglige vurderinger hadde Carstens arvet meget av den gamle bergmannsromantikk og sans for gamle bergmanntradisjoner. Dette kommer også til uttrykk i hans siste publiserte arbeid »Om Norges forråd av mutbare malmer« som han avslutter slik: »Den lyse skinnende kisen nede i de mørke gruverommene er jo eventyret for os bergmenn. Og vi håper — som barna — at eventyret aldrig skal ta slutt.«

Hans vakre hjem Saxenborg i Trondheim var alltid samlingsstedet for bergingeniører og geologer på gjennomreise og dannet et kultursentrum for norske bergmenn.

Ved Carstens død har norsk geologi og den norske bergetat lidd et uerstattelig tap.

Vi som har hatt den glede å samarbeide med Carstens vil alltid minnes ham som en fremrakende fagmann, en usedvanlig rikt utviklet personlighet og en god venn.

Vi vil hedre hans minne ved å reise oss.

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47. Professor dr. J. H. L. Vogts forskervirksomhet (Foredrag i Norsk geol. Forening 1. mars 1932.) (Norsk geol. Tidsskr. Bd. 11, 1932, s. 440—453.)
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49. Eisen- und Manganwiesenerze in Tarmfjorddal. (Zeitschr. f. prakt. Geologie, 1933, S. 113—117, 5 Abb.)
50. Tridymit als Schlackenmineral. (Centralblatt f. Min. etc. 1933, S. 321—322, 2 Textfig.)
51. Zur Genesis der Kiesvorkommen des Trondhjemgebiets. (Norges tekniske Høiskole, Avh. til 25-års jubileet 1935, s. 171—208, 3 Textfig. Også i Det kgl. norske Videnskabers Selsk. Skrifter, 1935.)
52. Zur Genesis der norwegischen Schwefelkiesvorkommen. (Zeitschr. d. deutschen geol. Gesell. Bd. 88, 1936, S. 257—268, 2 Textfig., 2 Tafeln.)
53. Norges svovelkisforekomster. Resumé av foredrag. (Tidsskr. kjemi bergv., 1936, s. 41 f.)
54. Om antimonforekomster. (Det kgl. norske Videnskabers Selsk. Forh. Bd. ,9, 1936, s. 85—88.)
55. Om malmforekomstenes forhold i dypet. (Naturen, 1936, s. 168—177.)

56. A. Det faste fjell. (Strinda Bygdebok, 1. hefte, 1937, s. 1—18, fargelagt geol. kart, 4 tekstfig.) C. Eiendomsretten til mineraler og bergarter. (l. c. s. 29—32.)
57. Plumosit von Forvik, Helgeland (Norwegen). (Det kgl. norske Videnskabers Selsk. Forh. Bd. 10, s. 83—85.)
58. Berthierit (Eisenantimonglanz) von Ringvassøy (Norwegen). (Det kgl. norske Videnskabers Selsk. Forh. Bd. 10, 1937, s. 86—88.)
59. Lauritz Dorenfeldt Jenssen. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 11, 1938, s. 30—32, 1 bilde.)
60. Bergtekniske definisjoner. (Tidsskr. f. Kjemi og Bergvesen, 1938, s. 38—40.)
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62. Kort oversikt over Norges jernmalmforekomster (oxydmalmer). (Teknisk Ukeblad, 1939, s. 195—197.)
63. Zur chemisch-mineralogischen Zusammensetzung der titanhaltigen Eisenerzvorkommen. (Norsk geol. Tidsskr. Bd. 19, 1939, s. 348—352, 2 Textfig.)
64. Et besøk i verdens eldste grube. (Tidskr. kjemi og bergv. 1940, s. 69—71.)
65. Zur Frage der Metamorphose der Schwefelkieserze. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 14, 1941, s 9—12, 1 Abb.)
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69. Ein neur Beitrag zur geochemischen Charakteristik norwegischer Schwefelkieserze. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 15, 1942, s. 1—4.)
70. Turmalin und Fluszspat als Bestandteile von Schwefelkieserz. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 15, 1942, s. 13—16.)
71. Über kupferhaltige Kiesvorkommen des Leksdalstypus. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 15, 1942, s. 161—164.)
72. Über den Co-Ni-Gehalt norwegischer Schwefelkiesvorkommen. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 15, 1942, s. 165—168.)
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76. Kobaltglanz als Bestandteil von Schwefelkieserz. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 18, 1945, s. 64—66, 1 Textfig.)
77. Über Pillow-tekstur im Schwefelkieserz. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 18, 1945, s. 79—83, 1 Textfig.)

78. Sammensetningen av norske ilmenitter I. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 18, 1945, s. 83—86, 1 tekstfig.)
79. Sammensetningen av norske ilmenitter II. (Det kgl. norske Videnskabers Selsk. Forh. Bd. 18, 1945, s. 113—116, 1 tekstfig.)
80. Om den kjemiske sammensetning av Trondheimsfeltets kalkstener. (Norsk geol. Tidsskr. Bd. 25, 1945, s. 48—52.)
81. Hvorledes den forkastede Moltkegang ble funnet (sammen med J. G. Engzelius). (Tidsskr. f. Kjemi, Bergvesen og Metallurgi, 1946, s. 108—110, 4 tekstfig.)
82. Norges forråd av mutbare mineraler. (Tidsskr. f. Kjemi, Bergvesen og Metallurgi, 1950, s. 21—24.)
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PROFESSOR MARTIN A. PEACOCK

ved Toronto University døde den 30. okt. i fjor. Han var en av de få kjente utenlandske vitenskapsmenn som foruten å være medlem av vår forening også bidro til tidsskriftets trivsel ved publikasjoner. Hans betydningsfulle arbeid »On Rosenbuschite« ville han trykke i vårt tidsskrift fordi mineralet først ble funnet i Norge (Brøgger 1887).

Professor Peacock og jeg var nære venner og han var en velsett gjest i familien gjennom over 20 år. Han ble bare vel 50 år gammel og døde midt i en rik arbeidsdag. En internasjonalt ledende mineralog gikk bort med ham.

Professor Peacock var skotte og fikk sin utdannelse i Glasgow under Tyrrell. Som ung mann kom han til Victor Goldschmidts institutt i Heidelberg, hvor han gjorde seg så bemerket at Goldschmidt ved sin avgang gjorde alt for å få Peacock som sin ettermann. Men da var allerede nazitiden begynt i Tyskland og under det antijødiske riksstyre gikk instituttet langsomt i oppløsning. I en lang tid var Peacock knyttet til Harvard University som medarbeider hos prof. Palache — denne eiendommelige, sterke skikkelse i internasjonal mineralogi og krystallografi. — Sammen med Harry Berman som så tragisk ble drept ved en flyulykke under krigen var Peacock den sentrale kraft omkring Palaches arbeid med revisjonen av Danas Mineralogi. Den »nye Dana« er i ikke liten utstrekning Peacocks verk. Peacock var nå bæreren av dette rike miljøs tradisjoner; det er et følelig og smertelig tap for den internasjonale mineralogisk-krystallografiske vitenskap at hans rike evner, så dypt forankret i kulturelle og faglige tradisjoner i hans sinn, ikke lenger skal drysse kunnskap og glød utover verden.

Tom. F. W. Barth.

LITTERATUR

H. E BUCKLEY: *Crystal Growth.* — (XV + 571 sider, 169 figurer, 88 tavler). John Wiley & Sons, Inc. New York 1951, $ 9.00.

Denne boken behandler på en klar og fullstendig måte et tema som har fundamental betydning for mineraloger og petrografer: læren om krystallisasjon, eller, for å si det på en annen måte: krystallisasjonsprocessenes fysikalske kjemi, teoretisk og praktisk. Røntgenstråler og strukturlære har jo i de senere årtier helt behersket krystallografien, la oss nevne landemerker som Buergers X-Ray Crystallography i 1942, Zachariasens Theory of X-Ray Diffraction in Crystals i 1945, Lonsdales Crystals and X-Rays i 1948.

Buckleys bok ligger på et annet område. Den behandler eksempelvis Stranskis og Kossels krystallisasjonsteorier, feil i krystallgitteret, ideal- og realkrystaller, habitus, forurensninger, blandkrystaller, parallelle sammenvoksninger, overflatefenomener ved vekst og oppløsning, krystallisasjon fra smelter og andre væsker, fra damper og gasser, og de dermed forbundne kjemiske forandringer; dendriter, sfæruliter, kurvede krystaller etc. etc.

Figurene og de fotografiske tavler er klare og illustrerende og gir sammen med teksten foruten teoretisk informasjon også en mengde praktiske opplysninger om apparatur for eksperimentell fremstilling og undersøkelser av krystaller og deres egenskaper.

Tom. F. W. Barth.

TOM. F. W. BARTH: *Volcanic Geology, Hot Springs and Geysirs of Iceland.* Carnegie Institution of Washington, 1950. 174 sider, kvartformat.

Island er en forunderlig øy. At den interesserer oss nordmenn av historiske grunner er en sak for seg. De egenartede naturforhold — varme kilder, geysirer, vulkaner og jøkulhlaup — øver en tiltrekning som er almen og bringer vitenskapsmenn og turister til øya fra mange land. For geologer må den i særlig grad være en fengslende arbeidsmark. Petrografen, geofysikeren og geokjemikeren kan der gå omkring i et naturens laboratorium og se reaksjoner skje som de ellers for det meste må slutte seg til ved studium av erosjonsrester fra fortiden eller forsøke å ettergjøre i liten skala selv. Og reaksjonene skjer i mange tilfelle med dramatisk fart og voldsomhet.

Ved lesningen av Tom. Barths bok får en da også inntrykk av at han i høy grad har vært fengslet av stoffet. Og han har formådd å gi skildringen av naturkreftenes spill slikt liv at også leseren, som til å begynne med titter hist og her gjennom boka, blir grepet av lyst til å følge med i hans tydning av det som skjer.

Boka bygger på forfatterens feltundersøkelser i 1934 og 1937 og på laboratoriearbeid og imponerende litteraturstudier. Den har fire avsnitt, nemlig de tre som tittelen antyder og dertil en fjerde del: »Description of Hot Spring Areas«. Hvert avsnitt slutter med en omfattende litteraturliste. Arbeidet tar særlig sikte på å beskrive kildevirksomheten, forklare hvor vannet og dets innhold av oppløste stoffer stammer fra, og gjøre rede for årsakene til geysirfenomenet og termalaktiviteten. Forfatteren legger vesentlig vekt på faktiske målinger og observasjoner og han gjennomgår og vurderer kritisk de mange teorier som i tidens løp har vært fremsatt om disse problemene.

Fremstillingen er rikt illustrert. Foruten kartskisser og andre tekstfigurer er der en rekke plansjer med større kart og i alt 67 instruktive og vakre fotografier. Enkelte av tekstfigurene synes å ha vært beregnet på å skulle forminskes noe, men det er allikevel ikke for sterkt sagt at publikasjonen utstyrsmessig og i formell henseende står i særklasse. Det gir faktisk en estetisk glede å bla igjennom den.

Sven Føyn.

NORSK GEOLOGISK FORENING

Møte 326. Torsdag 26. oktober 1950.

Til stede 31 medlemmer, 8 gjester.

Siden forrige møte var *C. W. Carstens* avgått ved døden.

Formannen overbrakte takk fra Dansk Geologisk Forening til dem som hadde deltatt som ledere av deres ekskursjon til Norge i sommer.

Innbydelse til Nordisk Geologmøte i København i mai, 1951 ble referert.

Ivar Oftedal ga en melding om en *ny nordnorsk mineralforekomst.* Trykt i bind 28, s. 234. H. Bjørlykke uttalte seg etter foredraget.

Foredrag av *Harald Carstens: Snåsasynklinalens stratigrafi og tektonikk.* I ordskiftet deltok: S. Foslie, O. Holtedahl, L. Størmer, C. Bugge, T. Barth, H. Rosendahl, T. Gjelsvik, N. Spjeldnæs og foredragsholderen.

Ekstraordinært møte torsdag 9. november, 1950.

Geologisk auditorium, Blindern.

Til stede: 15 medlemmer, 11 gjester.

Lektor J. P. Andersen, Viborg, holdt foredrag om: *De danske tertiære moler-lag og deres fossiler.* Foredraget ble ledsaget av lysbilder og fremvisning av fossiler og bergartprøver.

Limfjorden er mod øst smal og omgivet af flade enge, den hævede havbund fra litorinatiden. Mod vest er fjorden bred med uregelmæssig kystlinie. Bakkelandet går mange steder ud til kysten og danner klinter med lag både fra istiden og fra undergrunden. Ved foden af klinterne findes en broget blanding af løse blokke: Kalk og flint fra Danmarks egen undergrund og erratiske blokke fra Skandinavien. Blandt dem indtager de norske ledeblokke rombeporfyr og larvikit en fremtrædende plads.

Molerlagene er fra eocæntiden. De kommer frem i klinter og grave i det vestlige Limfjords-område, og de danner der nogle af de højeste klinter. De vigtigste forekomster er Silstrup i Thy, det nordlige Mors med Hanklit, Feggeklit, Skarrehage, Ejerslev m. m., Fur, og Ertebølle i Himmerland.

Molerserien består af skifer forneden og derover moler med cementsten og vulkansk aske. Moleret består af mikroskopiske kiselskaller blandet med lidt lersubstans. Cementstenen er en kalksten, der danner lag og boller i moleret. Den består af molerets bestanddele imprægneret med kalk.

Askelagene nummereres fra et nulpunkt opad og nedad fra ÷ 39 til +140. I den positive serie er der mange tætliggende askelag, i den negative færre med større intervaller.

Molerlagene er på de fleste forekomster stærkt foldede og forskudte som følge af istryk i istiden.

Molerlagenes inddeling og askelagenes nummerering hviler på en grundig undersøgelse af O. B. Bøggild. I sin afhandling »Den vulkanske Aske i Moleret«, 1918, skriver Bøggild, »Det er at forvente, at en så fuldkommen og i Enkeltheder gaaende relativ Tidsfæstelse, som Askelagene giver, ogsaa maa kunne faa nogen palæontologisk Betydning; men hidtil er der ikke udrettet det mindste i denne Retning«. Det gjaldt den gang, og det gælder så nogenlunde den dag i dag. Som årsager vil jeg bl. a. nævne: Det er vanskeligt at samle i de faststående lag, det vil sige, det er besværligt, og udbyttet bliver ringe i forhold til den anvendte tid og arbejde. Fossilerne i molerlagene er så forskjelligartede — diatomeer, radiolarier, planter, echinodermer, mollusker, insekter og fisk —, at ingen enkelt forsker vil kunne gennemarbejde fossilindholdet. Der vil dertil kræves specialister i de forskjellige grupper.

Den eneste gruppe, der er foretaget en grundigere bearbejdelse af, er insekterne i Kai L. Henriksens afhandling, »Eocene Insects from Denmark«, 1922, en god bearbejdelse af et lille materiale. Så at sige alle fundene er gjort i løse blokke og derfor ikke niveaubestemte.

Molerlagene indeholder fossiler både fra dyreriget og planteriget, både marine og terrestriske former. Fra land er der planter og insekter, fra havet echinodermer, mollusker og fisk.

Foredragsholderen gennemgikk fossilerne i hovedtræk med udvalgte eksempler fra de forskellige grupper:

Mikroorganismer: Diatomeer, dictyochider og radiolarier.

Planter: Ved og aftrykk af blade.

Echinodermer: Slangestjerner og søstjerner.

Mollusker findes i modsætning til de fleste andre tertiæraflejringer i ringe tal. Der er nogle få arter af muslinger og snegle. Cassidaria er den almindeligste.

Insekter er et af de vigtigste faunaelementer. Insekter er iøvrigt ikke almindelige i europæisk tertiær. Derimod er der en rig eocæn insektfauna i U. S. A., Rocky Mountains. De fleste insekter er fragmentariske ligesom fiskene. Det tyder på transport i strøm og bølgegang. Der er bl. a. fundet græshopper, ørentviste (norsk: saksedyr), tæger, cikader, netvinger, biller, sommerfugle og stankelben.

Fisk findes hyppigt, som oftest i fragmenter. Der findes arter af sildefamilien, makrelfamilien, Sparidæ og nålefisk. Fiskeskæl er almindelige, især i skiferlagene. Hyppigst er skæl af sildefamilien.

Det er givet, at selv om der er indsamlet et betydeligt materiale i molerserien, men materialet ikke er gennemarbejdet, bør man være forsigtig med at drage slutninger.

Fisk og insekter går gennem hele lagserien. Fisk er temmelig jævnt fordelt, mens insekter har maksimum i niveau 15—30. Som et kuriosum kan jeg nævne, at store græshoppevinger, så vidt jeg ved, kun er fundet på Fur, og de, der kan niveaubestemmes, er alle fra niveau 25—31.

Bunddyrene, echinodermer og mollusker, findes kun i de negative og nederste positive lag. Det ligger nær at tænke, at bunddyrene ikke har kunnet trives under de voldsomme tertiære vulkanudbrud, enten fordi de er blevet dækket af tykke askelag, eller eruptionerne har tilført vandet stoffer, der er ugunstige for bunddyrene.

Med hensyn til insekter nævner Henriksen, at der er mange tæger og stankelben, og det tyder på åbent land, »meadows near water«. Mine indsamlinger har relativt flere biller end Henriksen. Biller tyder på skovdækket land. Denne forskel kan sikkert til dels forklares ved, at Henriksens materiale hovedsagelig stammer fra de vestlige lokaliteter, mens jeg har samlet mest i den østlige del af molerområdet. Det tyder på, at der har vært mest skov mod øst. Det stemmer godt med de nævnte forhold, at man på lokaliteter med biller ofte finder vedstykker.

Et forhold, der måske også kan nævnes i denne forbindelse, er forskellen på lagtykkelse. Sedimentationen er større mod øst end mod vest. Det ses tydeligt på intervallerne mellem askelagene.

Trods disse forskelle må det dog siges, at molerlagene danner en serie af i det store og hele ensartede lag, hvori hovedparten af sedimentmaterialet stammer fra de kiselskallede organismer. Det blandede, heterogene indhold af forsteninger, både macro- og microfossiler, viser os, at lagene er aflejret i havvand med et stort indhold af kiselskallede planktonorganismer i nærheden af et land, hvorfra plantedele og insekter er ført ud, og denne aflejring er foregået, mens der i Danmarks nærhed var virksomme vulkaner med hyppige og til tider store udbrud.

Den vulkanske virksomhed, hvorved der gang på gang blev sendt store mængder af aske ud over omgivelserne, må naturnødvendigt have virket stærkt ind på livsvilkårene for de dyr og planter, der levede i den tid, både på land og i havet.

Litteratur.

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Stolley, E.: Über Diluvialgeschiebe des Londonthons in Schleswig-Holstein und das Alter der Molerformation Jütlands. Arch. f. Anthropologie und Geologie Schleswig-Holsteins 1900.

I ordskiftet etter foredraget deltok: L. Størmer, H. Major, J. A. Dons, H. Rosendahl og foredragsholderen.

Møte 327. Torsdag 16. november 1950.

Til stede: 29 medlemmer, 11 gjester.

Minnetale over *Carl Wilhelm Carstens* ble holdt av Harald Bjørlykke. Trykt i dette bind side 222.

Henrich Neumann: Geologien på kartblad Kviteseid.

Johannes Dons: Geologisk arbeid utført på kartblad Rjukan.

I ordskiftet etter disse foredragene deltok: W. Werenskiold, C. Bugge, S. Foslie, O. Holtedahl, T. Barth, H. Carstens, O. A. Broch, S. Føyn, O. Liestøl, T. Gjelsvik og foredragsholderne.

Møte 328. Torsdag 14. desember 1950.

Til stede: 29 medlemmer, 17 gjester.

Dr. Frank Mitchell: The Late Glacial Period in Ireland. I ordskiftet etter foredraget deltok: G. Holmsen, O. Holtedahl, H. Rosendahl, E. Dahl, P. Holmsen og foredragsholderen.

Rosendahls innlegg:

The highly interesting discourse of Franck Mitchell has confirmed the impression, that it is of great value for us to listen to the Irish geologists. Ireland, and Denmark, fill out parts of the evolution, that we lack. In Ireland we can follow he retreat of the ice from the border of the last glaciation. The isostatic uplift is only a small fraction of the corresponding Norwegian; hence the transgressions act a larger part. A special interest has dr. Mitchell's elucidation of the Allerød-period. A real renaissance is his motived hypothesis, that the Mammoth has lived in Ireland in the Allerød-period. In the deposits from that period is found the Giant Deer. Also in Denmark the Giant Deer is found in the deposits from the Allerød-period. If the Mammoth has lived in Ireland and in Siberia, it is not unlikely to have lived in Scandinavia too, as it formely was supposed.

Generalforsamling torsdag 15. februar 1951.

Til stede 30 medlemmer.

Årsmelding for 1950.

Siden forrige generalforsamling er 3 medlemmer avgått ved døden:
Professor Boris Popoff.
Bergingeniør C. W. Carstens.
Professor Lennart von Post.

I samme tidsrom ble følgende medlemmer innvalgt:

335. Rolf W. Feyling-Hanssen, Oslo.
336. Per Thorslund, Uppsala.
337. Margaret Espeland, Kolbotn pr. Oslo.

Foreningen har nå 195 medlemmer, herav 1 korresponderende medlem, 84 livsvarige medlemmer og 110 årsbetalende medlemmer.

Det ble holdt 7 ordinære og et ekstraordinært møte i det forløpne år, med tilsammen 283 deltakere.

Foreningen arrangsjerte en ekskursjon i Oslofeltet for Dansk Geologisk Forening.

Av tidsskriftet er bd. 28, h. 2—4 under trykning.

Utdrag av regnskapet for 1950.

Inntekter.

Beholdning, overført fra 1949: I kasse	Kr. 1 015,93	
I bank	» 5 924,34	
		Kr. 6 940,27
Innbetalt medlemskontingent for 1947	Kr. 15,00	
—»— —»— » 1948	» 90,00	
—»— —»— » 1949	» 195,00	
—»— —»— » 1950	» 375,00	
		» 675,00
Tilskudd fra staten		» 1 200,00
Tilskudd fra Sulitjelmafondet		» 1 250,00
Tilskudd fra Norges Almenvitenskapelige Forskningsråd		» 2 433,00
Abonnement og salg av tidsskriftet		» 1 948,75
Renter av bankinnskudd		» 112,39
Renter fra livsvarige medlemmers fond		» 338,06
Renter fra berg- og steinindustriens fond		» 407,51
		Kr. 15 304,98

Utgifter.

Tidsskriftet: Trykning, Bind 28, hefte 1		Kr. 2 433,00
Klisjeer		» 9,50
Arbeidshjelp, porto og skrivesaker		» 1 061,30
Møter og ekskursjoner		» 226,45
Rabatt ved salg av tidsskriftet		» 489,74
Representasjoner, anskaffelser og Reuschmedaljen		» 244,37
Beholdning, overført til 1951: I kasse	Kr. 843,23	
I bank	» 9 997,39	
		» 10 840,62
		Kr. 15 304,98

Livsvarige medlemmers fond.

		Inntekt	Utgift
1950 1. jan. Fondets kapital:			
Obligasjoner	Kr. 500,00		
Bankinnskudd	» 10 795,00		
Innbetalt kont. i 1950	» 455,00		
Urørlig kapital	Kr. 11 750,00		
Renter av obligasjoner og bankinnskudd		Kr. 344,06	
Forvaltning av verdipapirer			Kr. 6,00
Overført renter til ordinært budsjett			» 338,06
		Kr 344,06	Kr. 344,06

Berg- og steinindustriens gavefond.

		Inntekt	Utgift
1950 1. jan. Fondets kapital:			
Urørlig	Kr. 20 000,00		
Disponibel	» 5 554,00		
Renter for 1950		Kr. 407,51	
Overført renter til ordinært budsjett			Kr. 407,51
		Kr. 407,51	Kr. 407,51

Regnskapet revidert av S. Foslie og T. Strand, Oslo, 13. jan. 1951.

T. Winsnes og S. Føyn kom med spørsmål i anledning plaseringen av foreningens midler, som ikke kom fram av regnskapet. Formannen og S. Foslie svarte. Deretter ble årsmelding og regnskap godkjent.

Forslag om lønn til regnskapsføreren på kr. 500,00 for året 1951 ble godkjent med akklamasjon.

Reusch-medaljen ble tildelt *Chr. Oftedahl* for hans arbeide: Deformation of Quartz Conglomerates in Central Norway. Journal of Geology, Bd. *56*, s. 476—487, 1948.

Valg:

Formann: *G. Henningsmoen.*

Sekretær: *Nils Spjeldnæs.*

Viseformann: *Henrich Neumann.*

Styre: *Niels-Henr. Kolderup* (Bergens geologiske klubb), *Thorolf Vogt* (Trondheims geologiske klubb), *Per Holmsen, Sven Føyn.*

Redaktør: Det ble en del diskusjon om trykningen av tildsskriftet. I diskusjonen deltok: T. Barth, formannen, L. Størmer, T. Gjelsvik, F. Isachsen, H. Rosendahl, H. Bjørlykke, I. Oftedal, S. Foslie, H. Neumann. Generalforsamlingen ga styret fullmakt til å utpeke en hjelper for redaktøren, og til å stille midler til rådighet for tiltak til påskynding av tidsskriftets utgivelse. Deretter ble *I. Oftedal* gjenvalgt som redaktør.

Reusch-medalje-komiteen: *Chr. Oftedahl, L. Størmer.*

Revisorer: Gjenvalg av *Steinar Foslie* og *Trygve Strand.*

Varamenn for revisorer: *K. Kristoffersen* og *Tore Gjelsvik*

Forvaltningskomité for Berg- og Steinindustriens fond: *Carl Bugge, Olaf Holtedahl,* og *Gunnar Holmsen.*

Møte 329. Torsdag 15. februar 1951.

Til stede 30 medlemmer og 6 gjester.

Siden forrige møte var *Martin Alfred Peacock* avgått ved døden.

Innvalg av fire nye medlemmer ble godkjent:

338. Thor Siggerud, jr. Jomfrubråtveien 55, Bekkelagshøgda, Oslo.
Foreslått av G. Henningsmoen og H. Major.
339. Fredrik Hagemann, Blindern studenterhjem, Oslo.
Foreslått av G. Henningsmoen og H. Major.
340. Thane H. Mc.Culloh, 620 Norumbega Heights, Monrovia, California, U, S. A.
Foreslått av Tom. Barth og H. Major.
341. Otto Mellis, Fil. Dr., Mineralogiska Institutionen, Uppsala.
Foreslått av A. Heintz og H. Neumann.

Kort melding fra *Fridtjov Isachsen: Innergrensen for løsfund av flint og Oslostein i sydvestkystens moreneavsetninger.*

I ordskiftet deltok: H. Bjørlykke, E. Dahl og foredragsholderen.

Harald Bjørlykke: Bly- og sinkforekomster i Nord-Norge. I ordskiftet deltok: S. Foslie, O. Holtedahl, T. Gjelsvik, I. Oftedal, H. Neumann, B. Dietrichson og foredragsholderen.

Møte 330. Torsdag 8. mars 1951.

Til stede: 31 medlemmer og 6 gjester.

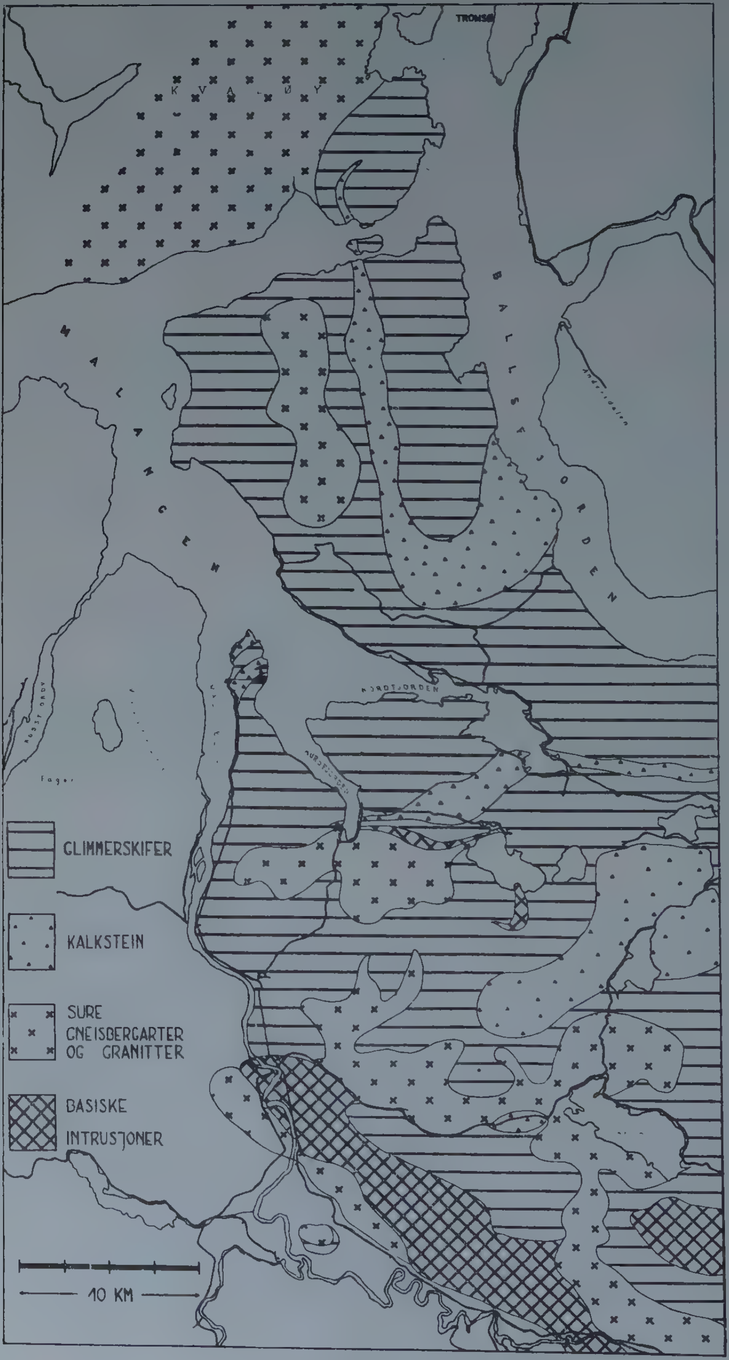
Innvalg: Professor Paul Michot, Institut de géologie, Université de Liège, Liège, Belgia (342), innvalgt som korresponderende medlem etter forslag av styret.

Stud. real. Gerd Vogt, Gyssestadkollen 25, Slependen (343), foreslått av G. Henningsmoen og N. Spjeldnæs.

Kaare Landmark: Tverrfolding i den kaledonske fjellkjede.

Foredragsholderen omtalte resultatene av sine tektoniske undersøkelser fra to områder av den kaledonske fjellkjede, nemlig midtre del av Troms fylke og strøket mellom Luster og Bøverdalen. Begge disse områder er sterkt preget av strukturretninger som stryker NV—SO. I tillegg til dette ble referert tidligere undersøkelser fra fjellkjeden, hvor samme strøkretning (»tverrfoldningen«) er omtalt. Enkelte av de hypoteser som har vært foreslått for å forklare tverrfoldningens genesis, ble omtalt.

I *Troms fylke* har foredragsholderen i noen somrer arbeidet med kartlegging av Målselv-bladet. Kartleggingen er ferdig for området øst og nord for selve Målselva. På det nordenforliggende kartblad Tromsø, har foredragsholderen foretatt oversiktsundersøkelser, slik at hovedtrekkene av den geologiske oppbygging er klarlagt for en del av området. Se kart 1. Hertil er oversiktsundersøkelser foretatt bl. a. på øyene Senja og S. Kvaløy.

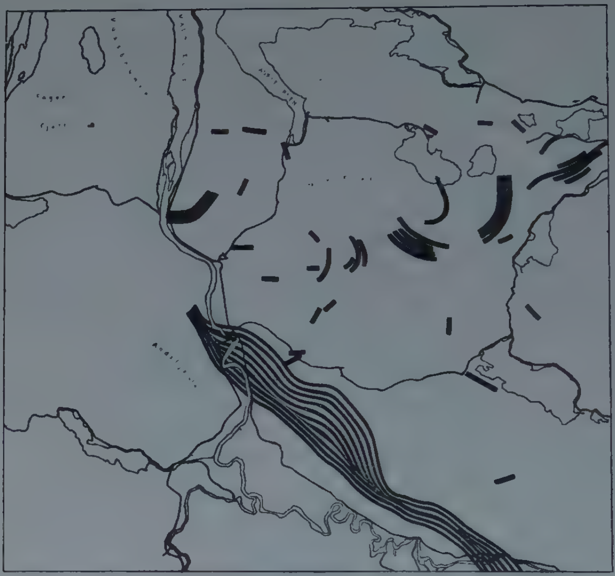

TROMSØ
KVALØY
MALANGEN
BALSFJORDEN
ROSSFJORD
Fager
NORDFJORDEN
AURSFJORDEN
GLIMMERSKIFER
KALKSTEIN
SURE GNEISBERGARTER OG GRANITTER
BASISKE INTRUSJONER
10 KM

Kart 1.

Målselv-bladet: Den vesentlige del av fjellgrunnen utgjøres av en storbladet muskovittskifer med mindre mengder biotitt. Den er nesten alltid granatførende. Kalkstein, med innleiret dolomitt, finnes vesentlig i ett nivå. Av basiske intrusjoner forekommer et mektig parti uralittgabbro (i Mauken), samt mindre mektige lagerganger, som vesentlig er amfibolittiske. Yngre enn disse gabbroide bergarter er sure intrusjoner, som dels har karakteren av mikroklinførende gneisgranitt, dels utgjør planskifrige lag av en aplittisk karakter. Over hele Målselvbladet befinner man seg stort sett i nær samme nivå i lagpakken. Under det omtalte kalklag opptrer kvartsitt- og kalk-konglomerat, som antas å svare til Evenskjærkonglomeratet fra Ofot-traktene. Studerer man lagrekken fra de lettest tilgjengelige steder, nemlig hovedvegene og fjordene, får man inntrykk av en serie som viser en rolig utformet tektonikk, nemlig overveiende et moderat fall av skifrighetsplanet i retning mot nord til nordvest. Så enkle er imidlertid forholdene ikke. Markerte folder sees noenlunde jevnt fordelt over hele kartbladet. Det dreier seg ofte om lukkete folder og rene isoklinalfolder. Enkelte folder nærmer seg overskyvningsfolder, men dette synes ikke å være det vanlige. Det ble vist kart hvor akser for observerte folder var inntegnet. Den herskende strøkretning for aksene ligger i sektorene NV—SO. Enkelte folder viser imidlertid strøkretningen SV—NO, altså parallelt fjellkjedens hovedretning. Aksenes stupning er praktisk talt moderat overalt, —20 til 30°. Der ble vist et rosediagram hvor aksenes strøkretninger var avsatt, konstruert på grunnlag av 67 observasjoner. Diagrammet viser et uttalt maksimum for en strøkretning på 120—130°. Stupningens retning er omtrent likelig fordelt mellom NV og SO. Et rose-diagram over linjestrukturer, basert på 47 observasjoner, ble også forevist. Dette viser et ennå mer markert maksimum for en strøkretning på 120°. Foruten ved de oversiktlige folder, er omradet karakterisert ved større anlagte folder, som, over tildels brede soner, har gitt lagene en helt steiltstående stilling. Disse lags strøkretning viser samme orientering som foldningsaksene, nemlig overveiende NV—SO, og i et mindre antall tilfelle, SV—NO. Karakteristisk er at de steile lag svinger fra »tverretningen« NV—SO til »hovedretningen« SV—NO, slik at man på flere steder får en utpreget »buestruktur«.

På kart 2 er avmerket lag som har en fallvinkel på 70 til 90°. Lag med så steile fallvinkler må være foldet etter akser hvis strøkretning ikke kan avvike mer enn maksimalt 12° fra lagenes strøkretning. På kart 3 er forsøksvis inntegnet ledelinjer for foldningsaksene, ved å kombinere observasjoner for direkte observerte foldningsakser og strøkretninger for de steile lag.

Akseretningen NV—SO er, som man vil se, sterkt dominerende. De bueformete områder må oppfattes som snitt gjennom domer og trau. En slik trauformet mulde utgjør det mektige parti av kalkstein omkring Sagelvvatnet, nær kartets østgrense. Slike domer og trau av dimensjoner på et fåtall meter, er observert flere steder innen kartområdet, og må oppfattes som dannet ved en kombinasjon av foldesystemene SV—NO

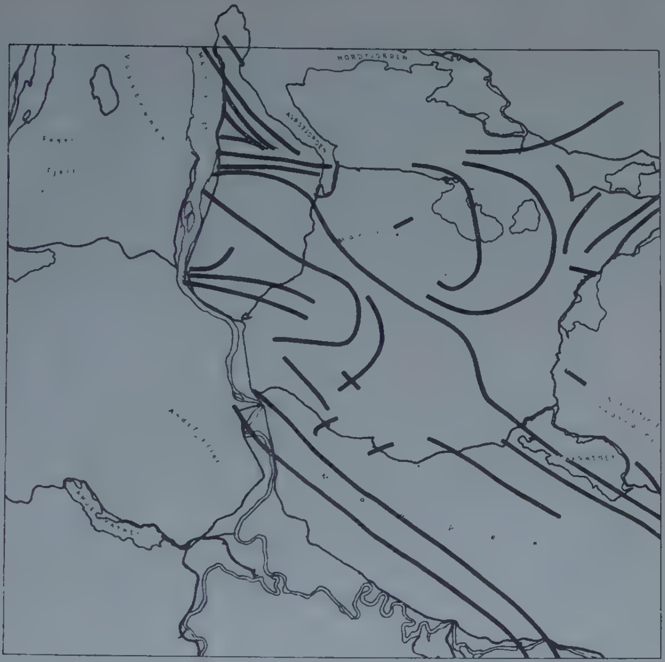


Kart 2.

og NV—SO. Det synes å dreie seg om lignende former som dem Foslie har omtalt fra Tysfjord-bladet.

Også innen *Tromsø-bladet* er folderetning NV—SO sterkt dominerende. Det kalklag som gjennomsetter halvøya mellom Balsfjorden og Malangen (se kart 1) utgjør således en mulde med akse etter nevnte retning. Det område som på denne halvøya er inntegnet som »sure gneisbergarter og granitter« består av finkornete, granodiorittiske gneiser som utvilsomt er genetisk forbundne med de nordenforliggende gneisbergarter på Kvaløya, og tilhører det kaledonske granittisasjonsområdet. Disse gneiser på Malanghalvøya utgjør det steiltstående sentralparti i en synklinal med strøk NNV—SSO. De sure gneiser som utgjør en vesentlig del av fjellgrunnen på Senjas og Kvaløyas østside har overveiende en steiltstående planstruktur, også med strøk omkring NV—SO som dominerende retning.

Resultatet av foredragsholderens undersøkelser i strøket *Luster—Bøverdalen* har tidligere vært publisert (B. M. Å. 1948). Grensene mellom de forskjellige avdelinger innen dette område følger stort sett et plan som stryker SV—NO, og har et fall på 25—35° mot SO. Fra underst til øverst har vi følgende bergartsavdelinger: 1) granitter, som oppad går over i granodiorittiske gneiser, 2) glimmerskifer, — omkring Bøvertun kalkstein, 3) sparagmittiske gneiser tilhørende Valdressparagmitten, 4) Jotun-eruptiver, mot grensen til Valdressparagmitten sterkt mylonittisert.



Kart 3.

De tektoniske forhold er her følgende: Grensene mellom lagene følger, som nevnt, vesentlig den kaledonske hovedretning. Glimmerskiferen viser overveiende en planstruktur som er konform med dette grenseplan. Det samme gjelder de øvre lag av basalgneisene under glimmerskiferen. De dypereliggende granitter viser imidlertid en markert foliation som stryker NV—SO og har helt steiltstående fall. I kalklagene ved Bøvertun sees både folder og steiltstående planstruktur som stryker NV—SO, altså etter tverrfordningens retning. I Valdressparagmitten alternerer den kaledonske hovedretning med tverretningen, på den måte at man i enkelte partier finner en vel utviklet skifrighet etter plan som stryker SV—NO og har et moderat fall mot SO, mens man i andre partier har en skifrighet med strøk NV—SŌ og helt steilt fall. I enkelte partier kan begge strukturretninger sees samtidig. Jotuneruptivene er ved skyveplanet mot Valdressparagmitten forgneiset til lag med skifrighet som er konform med den kaledonske hovedretning. Høyere opp i eruptivmassivet opptrer imidlertid hyppig en helt steiltstående foliation med strøk NV—SO. I samtlige disse avdelinger observeres en linjestruktur som stryker NV—SO. Denne kan sees meget markert, både i basalgranittene, — i kvartslinser i glimerskiferen, — i Valdresspanagmitten — og i Jotuneruptivene. Både i basalgranitten og i Jotuneruptivene er det ofte vanskelig å avgjøre om det bare foreligger denne linjestruktur eller om den nevnte foliation med steiltstående fall er tilstede. Et kvartskonglomerat i glimmerskiferen under kalksteinen nær Bøvertun viser en kraftig strekning parallelt nevnte linjestruktur.

Et foldesystem etter akser som stryker NV—SO er velkjent fra den kaledonske fjellkjede i Norge alt fra Törnebohms dager, så foredragsholderens undersøkelser viser bare at den også gjør seg sterkt gjeldende i de omtalte områder. Av andre områder hvor en folderetning med strøk mer eller mindre loddrett den kaledonske hovedretning gjør seg gjeldende, kan nevnes: Tysfjord-bladet og Hellemobotn — Linnajavre (Foslie), Nord-Rana (Th. Vogt og Jens Bugge), Stjørdalen (Törnebohm), Sunnmøre og Romsdal (Reusch, Trygve Strand), Vossestrand (Joh. Hødal), Sunnhordland (Reusch, Ruth Jacobsen), Gudbrandsdalen (K. O. Bjørlykke og andre), Bygdin (Trygve Strand), Tynset (Per Holmsen). Hvorvidt det i alle de nevnte tilfelle dreier seg om genetisk sett ett og samme foldesystem, får stå åpent. Det har hyppig vært diskutert om foldningen etter hovedretningen og etter tverretningen har foregått samtidig, eller om de tilhører forskjellige faser. Foredragsholderen mener, etter sine undersøkelser at det dreier seg om en og samme deformasjon som har frembragt de to systemer. Uten å ville trekke for store konklusjoner, peker foredragsholderen på den store likhet det er mellom buestrukturene på Målselvbladet og på Vestlandet.

Man kan nærmest oppstille 4 forskjellige hypoteser for hvordan den kaledonske tverrfoldning er kommet i stand: 1) Strand antar (for Bygdinkonglomeratet) at det har funnet sted en tri-aksial deformasjon under massenes skyvning mot SO, — vi har fått en massetransport også langs den tektoniske b-akse, d. v. s. langs hovedstrøkretningen SV—NO, — som har ført til en foldning parallelt skyveretningen. En slik forklaring finner foredragsholderen ikke urimelig for de høyereliggende, overskjøvne lag, men den forklarer ikke at tverretningen også gjør seg sterkt gjeldende i fjellkjedens migmatittområde.

2) Vi kan tenke oss at tverrfoldningen er kommet i stand ved at massene under skyvningen er presset mellom tilstedeværende, faste eruptivmassiver, (Th. Vogt, Nord-Rana). Denne forklaring synes bare å gjelde mer lokalt, og forklarer vel heller ikke at migmatittområdet ofte også viser den samme strøkretning som de overskjøvne partier.

3) En annen mulighet er at eruptivene har brudt fram samtidig med, eller senere enn skyvningen, og har presset lagene sammen etter tverretningen, (Carstens om tverrfoldningen i Stjørdalen). En slik forklaring synes vel å kunne gjelde for Målselv-bladet og Tromsøbladet. På Målselv-bladet har vi Maukens store gabbromassiv med lengdeakse NV—SO. På Tromsø-bladet har vi mektige lag av syntektiske gneiser med lengdeakse etter samme retning. Vi må i så fall tenke at en slik oppstuvning som framkaller tverrfoldningen kommer i stand ikke bare ved magmatiske frambrudd, men også ved en volumforøkelse på grunn av metasomatisk stofftilførsel under granittisering. Spørsmålet blir jo da imidlertid hvorfor disse massetilførsler så ofte synes å ha foregått langs lengdeakser som stryker NV—SO. Herved føres vi over i det fjerde alternativ:

4) Wegmann går ut fra at grunnfjellet under sedimentpakken i fjellkjeden overveiende har hatt strøkretningen NV—SO. Ved migmatiseringsprosessen i fjellkjedens sentrale del har så kaledonske migmatitter hatt en tendens til å bli preget av samme strøkretning, av den årsak at de surere lag av de gamle grunnfjellsgneiser først er blitt aktivert under migmatiseringen. Man kan kanskje bruke det uttrykk at det i underlaget er blitt dannet skinner, som har dirigert retningen for strukturen i de overliggende lag. På denne måte, mener Wegmann, kan man få en overgangssone over migmatittfronten hvor begge retninger gjør seg gjeldende, — den kaledonske hovedretning og den gamle grunnfjellsretning. En slik forklaring synes ikke urimelig om man betrakter lag som ikke ligger særlig langt unna migmatittfronten, slik som f. eks. området på kartblad Tromsø. Etter foredragsholderens undersøkelser i strøket Luster—Bøverdalen synes det imidlertid her som basalgranitten, med tverretningens struktur tilhører grunnfjell som *ikke* har vært aktivert i kaledonsk tid i dette området. Det har bare langs skyveplanet under glimmerskiferen funnet sted en forskifring av basalbergarten så denne har fått en planstruktur parallelt skyveplanet. Det blir da vanskeligere å forstå at samme strøkretning, NV—SO, skal gjøre seg gjeldende fra dypere nivå i basalgranitten og like opp i Jotuneruptivene. Sikkert er det imidlertid at vi flere steder i fjellkjeden finner at den samme »tverretning« gjør seg gjeldende både i basalgneisene eller -granittene under fjellkjedesedimentene og langt opp i skyvedekkene. Foredragsholderen mener at Wegmanns idé vanskelig lar seg se bort fra for å forklare dette, selv om ikke alle detaljer i årsaksforholdet lar seg klarlegge.

I ordskiftet etter foredraget deltok: O. Holtedahl, B. Dietrichson, P. Holmsen, T. Strand, C. Bugge, T. Gjelsvik, L. Størmer, H. Rosendahl og foredragsholderen.

P. Holmsens innlegg:

Tverrfoldningen i den kaledonske fjellkjede er et begrep som også tidligere har vært påaktet og diskutert blandt geologene. Det karakteristiske ved denne retning er at den er parallell med skyveretningen. Den er dermed også parallell med strekningsretningen av bergartene, noe som er blitt belyst bl. a. ved det arbeide i Journal of Geology av Chr. Oftedahl som i dag er blitt belønnet med Reusch-medaljen. Selv har jeg omtalt dette fenomen i arbeidet: Geologiske og petrografiske studier i området Tynset—Femunden, på side 50, under beskrivelsen av de tektoniske forhold ved Sålekinna. Over den autochtone sparagmittserie her, som er stuvet sammen i steil lagstilling, kommer Sålekinnas overskjøvete sparagmitter i hvilke det opptrer »tverrfolder« (i Landmarks terminologi) som har akseretningen N 30°—40° V med svakt fall i denne retning. Skyvningene har foregått i den motsatte retning, mot sydøst, og denne retning har også friksjonsstripene og konglomeratbollenes lengste akse i hele dette område.

Om hvordan slike tverrfolder oppstår, har Robert Balch gitt en inngående forklaring i: »Geologic structures of sedimentary rocks«, Bull. of Geol. Soc. of Am., Vol. 47. No. 5. 1936. Han forklarer tverrfoldene på den måte at foldene er oppstått under selve skyvebevegelsen, som et resultat av krefter som virker på tvers av skyvebevegelsen, beroende på ujevnheter i underlaget og inhomogeniteter i selve det bevegelige kompleks, slik at deler av dette opptrer som selvstendige blokker. Presses en av disse blokker mellom to nabo-blokker, f. eks., oppstår tverrfoldning.

Det kan være interessant å merke seg at en geolog som Sander benekter eksistensen av folder parallelt med skyveretningen.

C. Bugges innlegg:

Under mine studier i den kaledonske fjellkjede er jeg også kommet inn på det spørsmål som foredragsholderen har behandlet i sitt foredrag og som han kaller tverrfoldene i fjellkjeden.

Jeg er kommet til den oppfatning at fenomenet ikke er så innviklet. Det har sin naturlige forklaring i de depresjoner og kulminasjoner som opptrer i fjellkjeden.

Det har lenge vært kjent at det langs fjellkjeden strekker seg antiklinaler og synklinaler. På de steder hvor synklinalene har sin største depresjon ligger foldningsaksen horisontalt og lagenes strøk er paralell med fjellkjedens vanlige strøk, ca. NØ—SW.

Herfra stiger foldningsaksene til de ved kulminasjonen har fått sin største hellingsvinkel. Synklinalene har da lukket seg skålformet og har fått form av et langstrakt karr.

Lagseriens strøk er gradvis bøyet rundt til det i kulminasjonen går tvers på fjellkjedens strøk. Videre framover langs fjellkjeden vil foldningsaksenes hellingsvinkel avta og etter et kortere eller lengere stykke falle i motsatt retning. Synklinalene går så mot ny depresjon.

Synklinalenes foldningsakse følger således langs fjellkjedens lengderetning en bølgeformet linje. Synklinalenes underlag under geosynklinalsedimentene består av prekambriske bergarter i mer eller mindre regenerert form. En relikt strøkretning i de prekambriske bergarter er ofte synlig. Vanligvis er denne retning NW—SØ (gotisk og karelsk).

Jeg regner med 4 sikre kulminasjoner i den kaledonske fjellkjede i Norge, nemlig:

1. *Vestlandskulminasjonen.*

Bergensbuene og buene ved Haugesund — Karmøy finner herved sin naturlige forklaring.

2. *Otta-Dovrekulminasjonen.*

Den nordvest-sydøstlige strøkretning i Gudbrandsdalen forklares ved denne kulminasjon. Fra depresjon lenger nord i Trondhjemsfeltet og sparagmittfeltet kan man ved å følge lagene mot sydvest iaktta at strøket gradvis svinger fra NØ—SW til Ø—W og videre til NW—SØ etter som man nærmer seg kulminasjonen.

3. *Snåsakulminasjonen.*

I denne kulminasjon stiger opp fra syd mot nord foldningsaksene fra Trondhjemsfeltets synklinaler og et stykke lenger nord faller aksene i motsatt retning ned i synklinalen som over Grong strekker seg nordover. Tektonikken sees på Törnebohms kart og på kart Norden av Gavelin og Magnusson.

4. *Tysfjordkulminasjonen.*

Denne framtrer klart på Foslies karter. Håfjellmulden med nordfallende foldningsakser er meget tydelig utviklet. Det henvises til Foslies beskrivelse over strøkretningene som flere steder går tvers på fjellkjedens vanlige strøk.

Den synklinal som går ut mot syd i kulminasjonen ved Tysfjord brer seg nordover forbi Gratangen, Salangen, Målselv og har antagelig sin nordlige kulminasjon i partiet Kvænangen—Alta—Repparfjord, hvor Kaledonidene krysser Karelidene. Denne 5te kulminasjonen er ennå lite undersøkt. Den ser ut til å ligne Otta-Dovrekulminasjonen, hvor Kaledonidene krysser Gotidene. En eiendommelighet ved disse 2 kryss er bl. a. at det ikke er utviklet Støren-Bymarks grønnstensformasjon, i all fall ikke i den form man kjenner den i Trondhjemsfeltet og Vestlandet.

Det viser seg således at den såkalte tverrfolding i fjellkjeden kan forklares på en enkel måte ved kulminasjoner. Jeg har utarbeidet et manuskript til en publikasjon om fjellkjeden og det jeg her har sagt er et utdrag av et avsnitt om depresjoner og kulminasjoner i fjellkjeden.

For å få et fullstendig billede av det som er foregått må man søke å følge den orogene periode hos Kaledonidene i hele dens utvikling.

MELDINGER, PERSONALIA

Universitetet i Oslo.

Preparant *Alf Granli,* Mineralogisk museum, er 28. april 1951 tildelt H. M. Kongens fortjenstmedalje i sølv.

Assistent *Ivar Hernes* har våren 1951 fullført matematisk-naturvitenskapelig embetseksamen med mineralogi-petrografi som hovedfag. Avhandling: »Molde-feltet. En undersøkelse av Moldehalvøyas eklogitfelter og marmorfelter.«

Cand. mag. *Tor Ørvig* er våren 1951 kreert til dr. philos. på sin avhandling »Histologic Studies of Placoderms and Fossil Elasmobranchs. I. The Endoskeleton, with Remarks on the Hard Tissues of Lower Vertebrates in General.«

Cand. real. *Harald Carstens* har i 1951 permisjon fra sin stilling som vitenskapelig assistent ved Mineralogisk institutt for med Fulbright-stipendium å oppholde seg ved University of Minnesota. Som vikar fungerer stud. real. *Thor Siggerud.*

Cand. real. *J. A. Dons* er ansatt som vikar i konservatorstilling ved Mineralogisk-geologisk museum fra 1. juli 1951.

Cand. real. *B. Andersen* er ansatt som vikar for vitenskapelig assistent ved Geologisk institutt fra 1. juli 1951.

Professor dr. *Tom. F. W. Barth* oppholder seg i U. S. A. fra 20. aug. 1951 til årets utgang. I hans fravær bestyres Mineralogisk-geologisk museum av førstekonservator dr. *H. Neumann.*

Norges Geologiske Undersøkelse.

Cand. real. *R. Selmer-Olsen* er ansatt som geolog fra 15. april 1951.

Direktør dr. *Carl Bugge* har ved oppnådd aldersgrense tatt avskjed 13. september 1951. Som ny direktør er tiltrådt cand. real. *Sven Føyn.*

Vegdirektoratet.

Cand. real. *Chr. C. Gleditsch* er ansatt som geolog ved Veglaboratoriet fra 15. april 1951.